

UNIVERSITY OF MIAMI

APR 18 1961

Astronautics

A PUBLICATION OF THE AMERICAN ROCKET SOCIETY

APRIL 1961



Rendezvous in Space Kurt R. Stehling

Deep-Space Communications Eberhardt Rechtin

SPECIAL SECTION ON NEW MATERIALS FOR SPACE VEHICLES



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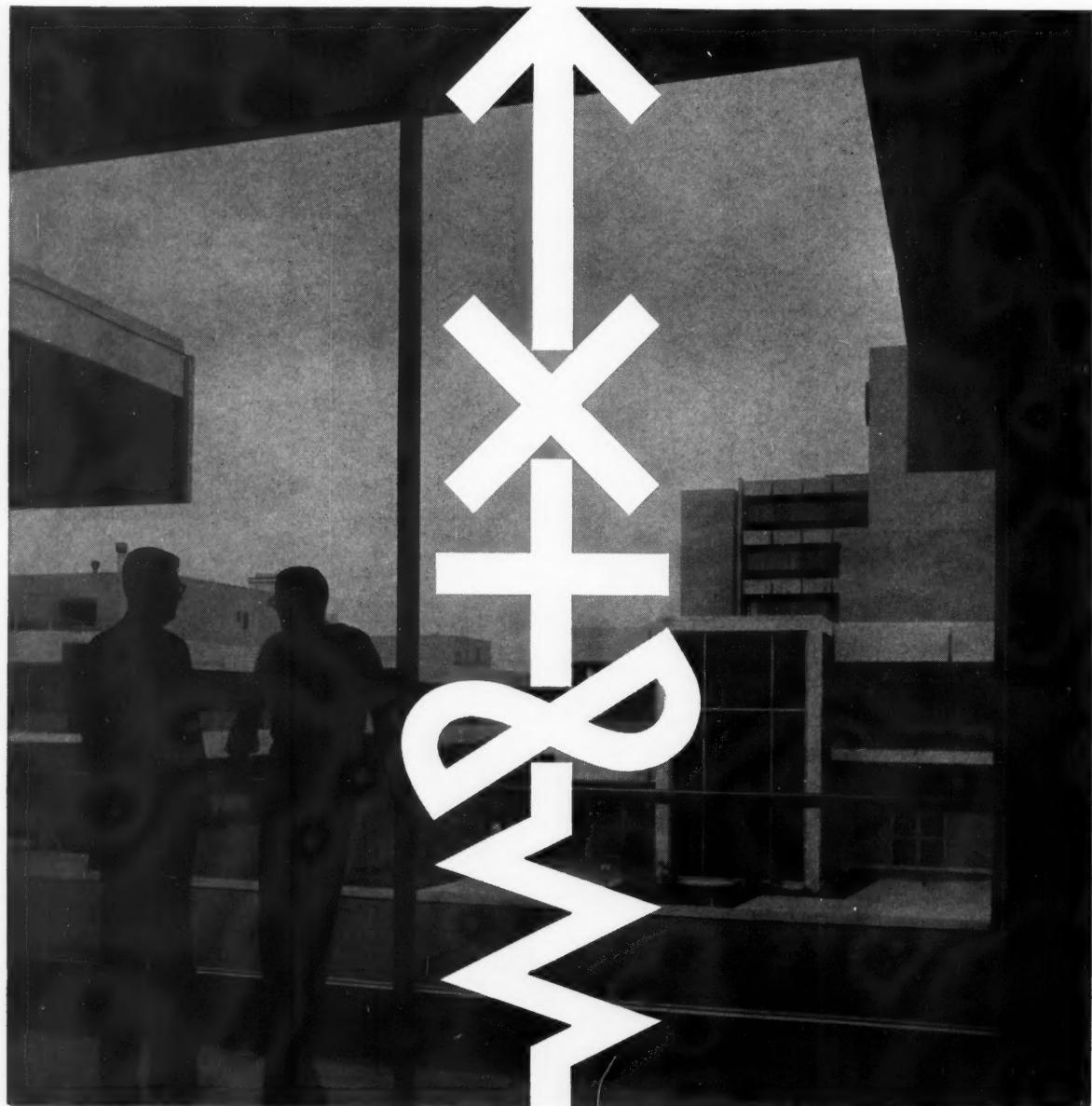
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COVER: The beauty of this cluster of sapphire whiskers will be matched by an unparalleled strength of high-temperature composite materials, representing a breakthrough in reinforced structures for space vehicles, if current investigations by GE's Space Sciences Laboratory for the Navy's Bureau of Weapons are successful. The whiskers exhibit a strength greater than 1,000,000 psi at room temperature and 150,000 at 3570 F. (ASTRO cover plaques 11 × 12 in. are available from ARS Headquarters at \$2.00 each.)

Astronautics

A PUBLICATION OF THE AMERICAN ROCKET SOCIETY INC.

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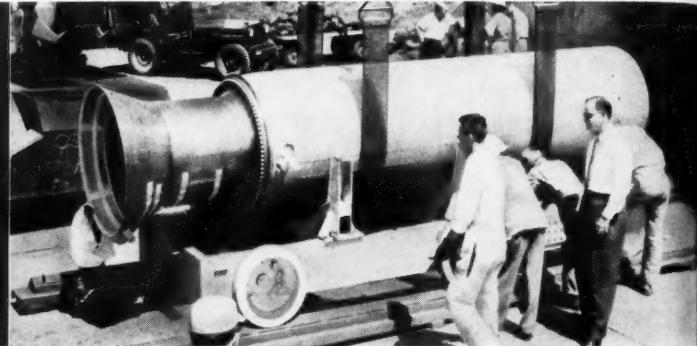
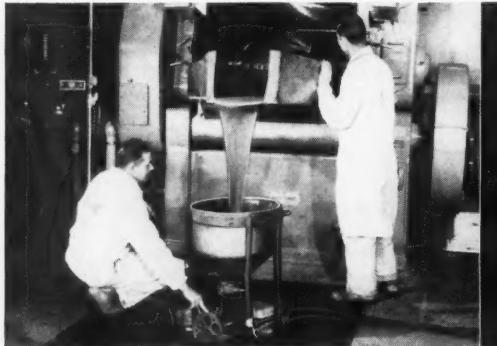
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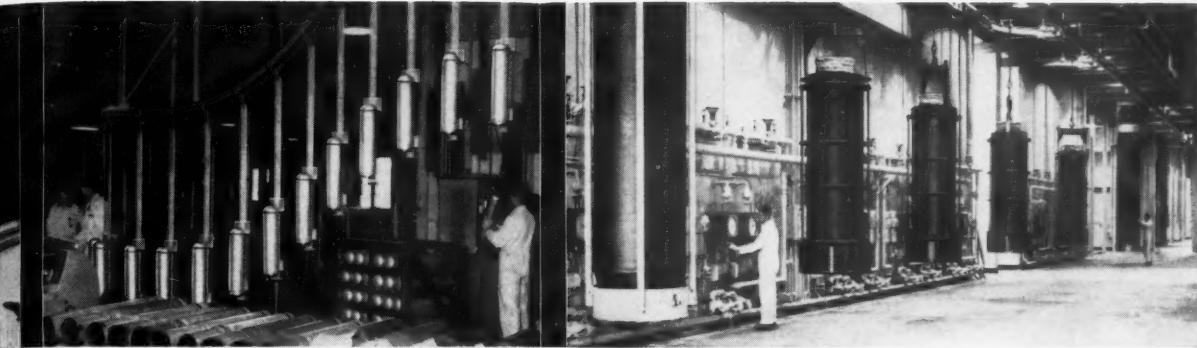


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flight tests with virtually 100% reliability. All have contributed mightily to advancing the total state of the art. Additional capabilities for Army's advanced thinking are provided by other Thiokol Divisions. Utah, for large engine production—RMD, for sophisticated liquid systems—and Elkton, for diversified special motors.

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THIOKOL

THIOKOL CHEMICAL CORPORATION, Bristol, Pennsylvania
Rocket Operations Center: Ogden, Utah

Astro notes

MAN IN SPACE

- The Russians orbited and successfully recovered Spacecraft IV after an estimated three trips around the earth. The feat put U.S. space planners on notice that Russia will possibly orbit an astronaut before the U.S. does, and perhaps even before a manned suborbital Redstone flight. Soviet scientists have chalked up a 2 out of 4 record with their 10,000-lb capsule. Flights in May and December 1960 failed on the re-entry phase of the maneuver; flights in August 1960 and last month were successful in returning animal passengers.

- The first American astronaut will be hurled to the edge of space in April, according to information reaching *Astronautics* at press time. He is to be preceded by one last "insurance" shot of the Redstone booster at the insistence of Werner von Braun, director of the Marshall Space Flight Center. Intended only to make sure all the bugs troubling the "improved" Redstone boosters have been eliminated, this MR flight will carry only a dummy capsule with no life-support or recovery systems. Convincing their capsule has proved itself in all important respects, NASA Space Task Group officials are pressing for the earliest possible manned flight following the proposed Redstone insurance shot.

- Project Mercury's biggest shot-in-the-arm came with the flawless performance of the capsule in its maximum-abort test in February aboard a beefed-up Atlas booster. (This vehicle featured a heavily reinforced nose section to overcome structural weaknesses believed responsible for the MA-1 failure last July.) In the Atlas test, the capsule was propelled to an altitude of 107 mi, a top speed of 12,850 mph, and a range of 1425 statute miles. It was subjected to a re-entry deceleration of 16.5 G and a higher heat pulse than would be experienced in a normal re-entry from orbit. Nevertheless, the interior temperature held at 90 F.

- As a result of the successful Atlas flight, STG announced that MA-3 would be an orbital-abort shot with a trans-Atlantic range. In this trajectory, the Atlas will insert the capsule into orbit, but the capsule

will immediately separate and fire its retrorockets and re-enter. It will not carry a chimpanzee, but a "crewman simulator" may be included as a mechanical test of the ability of the life-support system to supply oxygen and carry away carbon dioxide and moisture at the rate required by an astronaut. This flight could come in April, depending on delivery of the thick-skinned Atlas booster earmarked for the flight.

- Astronauts John Glenn, Virgil Grissom, and Alan Shepard were selected by STG Director Robert Gilruth to undergo special training at Cape Canaveral for the first Mercury-Redstone manned shot. Selection was based on medical, training, and other technical information accumulated during the 22-month training program, Gilruth said. He pointed out that all seven astronauts will remain eligible for later ballistic and orbital flights.

- STG has worked out a detailed flight syllabus to be performed by the astronauts manning the first two capsules. This includes attitude-control maneuvers with the most difficult manual-control mode (mechanical linkage), using position data provided first by capsule instruments and later by exclusive reference to the periscope display for roll, pitch, and yaw data. The astronaut will switch to the retro attitude and fire his retrorockets, and finally he will seek to "pilot" the capsule's attitude during the actual re-entry maneuver.

- The big hope of STG is that the astronauts will perform as well in the capsules during zero-G as they have in the various ground simulators. If this should be the case, it would mean that the existing Project Mercury training program is largely adequate to prepare men for space flight, and that preliminary suborbital flights are not necessary for the longer orbital flights planned aboard Atlas. On the other hand, the astronauts' space performance may fall markedly below their performance on similar "base line" runs with the Johnsonville centrifuge and other devices, indicating that the ground training program falls short of simulating the real thing.

- "The jury is still very much out on this question," commented a

psychologist with the Space Task Group. "You can see the question is extremely significant because of its cost implications. If we must schedule suborbital missions as a regular part of the training program, our manned space activities are going to be very much different from a situation in which we can orbit men without that particular preparation."

- The X-15 set another speed mark -2905 mph with USAF Maj. Bob White at the controls. It was the first flight of the X-15 with the 57,000-lb-thrust Thiokol-Reaction Motors rocket engine. The plane was flown at half-throttle during the speed run, the Air Force reported.

- An all-out speed run of 4000 mph and an altitude attempt of 50 mi are expected this summer; but they may not set new records for manned flight, as a manned Mercury-Redstone flight will come sooner, and it should propel an astronaut to 115-mi altitude and about 4400 mph at motor burnout.

- On March 9, the Russians orbited the fourth in their series of 5-ton Sputniks since last May 14, and returned it to earth safely "on command in a preset area of the Soviet Union" after 17 revolutions around the globe. The spacecraft carried one dog and did not eject a capsule, as did the two-dog vehicle of last August, but re-entered as a complete unit. This suggests that the Russians may have tested the complete life-support system for a man for the first time.

- News reports from Moscow indicated that there was some debate in Russian governmental and technical circles over the readiness of a Soviet vehicle to attempt a manned orbital flight. But as George Low of NASA commented, it looks as if they are "about ready to put up a man."

SPACE PROPULSION

- Interest continues to grow in the field of solid-rocket boosters for major space vehicles. A Thiokol proposal made to NASA early last month called for construction of a solid booster capable of lifting the whole Saturn C-2 vehicle to 5000 fps. A Thiokol spokesman offered that the booster, weighing 4-5 million lb, might be developed within 24 months for about \$20 million, on

Notable Achievements at JPL

MOON BOUNCE...a collaborative project of the National Aeronautics and Space Administration, the Jet Propulsion Laboratory, and the Australian Ministry of Supply to link two continents by radio signals bounced off the Moon

**TOTAL DISTANCE
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**ELAPSED TIME
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... for microwave and RF solid state circuit design and flight evaluation.

... for project management assignment on advanced development and contracted effort in space communications.

Physicists

... for analysis in communications theory, orbital mechanics, guidance and control, and systems performance.

... for analysis of digital communication and control systems; real-time digital computer and closed-loop systems.

... for research and development of servo and control mechanisms for large ground based and spacecraft antenna systems.

Other opportunities exist for electronic engineers and physicists in many areas at JPL which has been assigned the responsibility for the nation's Lunar, Planetary and Interplanetary unmanned exploration programs.

On February 10, 1961, California and Australia were linked in the first international space communication experiment that bounced voice messages between the two points via the Moon. The words were beamed at the Moon from the Jet Propulsion Laboratory transmitter at Goldstone, California to the receiver at Woomera, Australia.

Principals in the conversation were Dr. Hugh L. Dryden, NASA Deputy Director, whose voice was relayed from Washington by telephone; Dr. Lee DuBridge, President of California Institute of Technology, who spoke directly from Goldstone; and Alan Hulme, Australian Minister of Supply at Woomera.

The occasion tested the new Australian station, the second of three Deep Space Instrumentation stations developed and directed for the National Aeronautics and Space Administration by the Jet Propulsion Laboratory.

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a fixed-price basis. If accepted, the proposal, being given consideration by NASA, could conceivably revolutionize the rocket business.

- NASA's Marshall SFC continues to press studies of possible space vehicles beyond the Saturn class having first-stage thrust of 6- to 12-million lb. Early last month, Marshall issued six-month contracts for comprehensive vehicle studies to Convair (\$130,017), Lockheed's Georgia Div. (\$136,743), and North American Aviation (\$160,014).

- These new Marshall SFC contracts cover optimum use of nuclear propulsion in large rockets, desirability of attempting to recover and re-use large space vehicles, attractiveness of a large liquid hydrogen-liquid oxygen booster, solid and liquid propellants in first stages, conventional tandem staging versus parallel staging, pressure-fed versus pump-fed systems, etc. Conceptual designs and comparative cost analyses will be made for each configuration under the contracts, and the most promising configurations will be selected for further study.

- Development proposals involving some 26 companies are expected in the joint NASA-AEC competition for a contractor to develop the Rover nuclear rocket engine. Deadline for the proposals is April 3. The program has been designated Nerva, meaning Nuclear Engine for Rocket Vehicle Application, and will have an aggregate cost of about \$1 billion, according to a NASA estimate.

- The contractor group chosen for Nerva will prepare an engine design, a development program plan, and a program of assistance to the Los Alamos Scientific Laboratory of AEC in the conduct of the Kiwi-B reactor experiments. These are scheduled to begin late this year and will involve liquid hydrogen rather than gaseous hydrogen as the propellant, and liquid hydrogen instead of water as the coolant for the nozzle.

- An Air Force Blue Scout II drove a 172-lb payload of telescopes and other instruments to an altitude of 1580 mi at the Atlantic Missile Range. Using the same components as the NASA Scout, the USAF vehicle will eventually have a guided fourth stage. The USAF scheduled five more Blue Scout probes before a satellite attempt comes in September. By 1962, the Air Force expects to fire Blue

Scout probes and satellites at the rate of 35 a year.

- NASA estimates its total cost for developing the first-generation Scout booster at \$17 million. The amount includes 8 flight-test vehicles with a production and launching cost of \$935,000 each. Commencing with Scout No. 11 (the third operational booster), NASA will increase Scout payloads from 150 lb and 25-in. diam to 200 lb and 30-in. diam. This will be accomplished by using Polaris and Minuteman solid propellant in the Hercules third- and fourth-stage motors.

- Chance Vought won the NASA contract to supply 42 propellant tanks for the Saturn booster program, with delivery to begin in April 1962. The \$2 million award will provide 70-in. fuel and lox tanks for five Saturn systems, plus two spare tanks. Boeing, Chrysler, and Martin also placed bids.

- NASA-Marshall announced that the second series of static firing on the Saturn booster had been concluded successfully in February, and that it had begun preparations for static testing the first Saturn flight booster this spring. For a look at the Saturn flight-testing configuration, see page 89.

- Republic Aviation reported that it will expand its plasma-propulsion program and build one of the largest electrical-propulsion test facilities in the country. The company is now completing a prototype of a "production-model" plasma pinch engine, the third developed by it since 1958.

SATELLITES

- NASA succeeded on its second try in placing a 12-ft air density satellite in orbit with the four-stage Scout solid-propellant rocket. The solar-powered transmitter in the 15-lb "polka dot" sphere broke down before the first orbit was completed. The transmitter in the final-stage motor case confirmed that the assembly had attained the desired orbit (1604 mi apogee, 404-statute-mile perigee, and period of 118.5 min), and the Lincoln Lab's Millstone Hill radar confirmed that the sphere had inflated. The tracking network of the Smithsonian Astrophysical Observatory subsequently obtained photographic and visual sightings of the errant sphere.

- The Navy's third Transit satel-

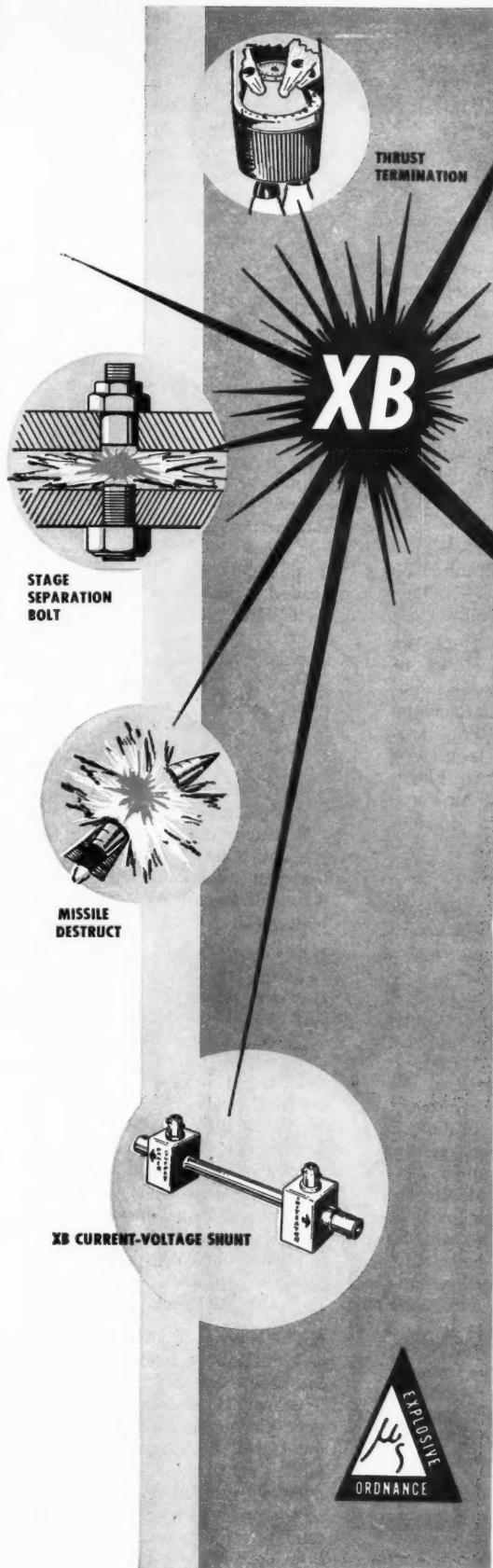
lite (III-B) was launched into a lop-sided orbit with a 54-lb ionospheric "hitch-hiker" designated Lofti, but the pair failed to separate from each other or the Agena-Star rocket. Because of the elliptical orbit (617-mi apogee and 104-mi perigee), it appeared that the Agena-Star engine failed to restart as planned, and that the balance of the sequence, including separation, could not be performed. The mishap shortened the life of the experiments and ruled out planned geodetic measurements, but the Navy reported that the Transit memory core was working well, and that Lofti was doing better than planned in its VLF studies of whistlers and man-made transmissions, because it traversed more of the ionosphere than planned on each pass. A circular 500-mi orbit has been planned.

- Clark Randt, director of the NASA Office of Life Sciences, has proposed a Biomedical satellite program using a modified Mercury capsule for long-duration animal flights. Dr. Randt proposes a total of four flights ranging from 2 to 14 days to explore the effects of prolonged weightlessness. One chimpanzee and two monkeys could be carried on a flight. One of the latter would be left unrestrained to determine the effects of a harness during zero-G.

- The Air Force whipped Discoverers XX and XXI into orbit a day apart. The latter launch marked the first actual use of the restart capabilities of the Agena-B rocket stage, adding four minutes to the satellite's orbital period. Discoverer XXI had no re-entry capsule since it was another infrared experiment in support of the Midas early-warning satellite. The 2450-lb Discoverer XX was to be called from orbit four days after launching, but this was prevented by a system malfunction. The recovery failure may defer a plan to orbit a 7-lb simian in the Discoverer XXII capsule.

COMMUNICATION SYSTEMS

- The tempo of the industrial struggle for a role in the communications-satellite field has picked up sharply. General Electric and Radio Corporation of America have formally announced their interest in active relay satellites, in opposition to American Telephone & Telegraph Co. And the Justice Department in a letter to attorneys representing Lockheed Aircraft hinted

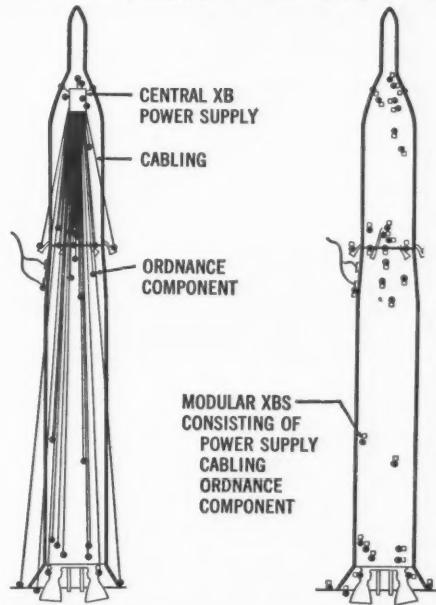


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that it may oppose control of the commercial communications-satellite field by a single company on anti-trust grounds.

• GE proposed to the Federal Communications Commission a "common carrier's common carrier" as the solution to the problem of private operation of communications satellites. It outlined a \$280 million system of 10 satellites in equatorial orbits at 6000-n. mi. altitude. Each of the equally spaced 1000-lb relays would have 600 two-way voice channels and a five-year lifetime. Such a system, including 18 ground terminals, could be ready by 1970, GE said, and could be operated as an independent international communications system serving and linking already existing carriers throughout the world.

• In another brief submitted to FCC, the Radio Corporation of America proposed a system of three synchronous equatorial relay satellites. It said it is studying the idea with Lockheed Aircraft, General Telephone and Electronics Corp., and other firms, with the objective of establishing a satellite system "as a service to all carriers."

• AT&T in a brief of its own stoutly defended its proposal for 40 active-relay satellites in 3000-mi orbits, and urged the promptest possible government action to avoid jeopardizing the U.S. lead in communications satellites.

• NASA postponed until March 20 the deadline for proposals on its Project Relay active repeater satellite. The two-week extension was ordered because of a decision to add two new bands to its operation. These included 5924 to 6425 mc for ground-to-space and 3800 to 4200 mc for space-to-ground. The frequencies initially specified to bidders were 400-500 mc for the ground-to-satellite link and 2200-2300 mc for the satellite-to-ground.

• The civilian space agency was also moving forward with its passive-satellite program. It awarded the G. T. Schjeldahl Co. of Northfield, Minn., a \$400,000 contract to manufacture 135-ft three-layer Echo spheres capable of maintaining shape in space. Initial launch of the new satellites is scheduled next year aboard a Thor-Agena-B from Vandenberg AFB. In late 1962 or early 1963, an Atlas-Agena-B will orbit three of the 135-ft spheres at 1700-mi altitude as the first installment of Project Rebound.

A year later, the Centaur vehicle will orbit six of the spheres.

• Beckman Instruments Systems Div. received two contracts totaling \$1.808 million from Lockheed Missiles and Space Div. for its Programmable Integrated Control Equipment to be used in Air Force satellite programs.

• GE's Missile and Space Vehicle Dept. completed an experimental version of its Syncholink telemetry system, which employs pulse code modulation with phase-shift keying. GE expects this system to exceed the performance of any deep-space communications link developed to date, including Pioneer V's.

• Westinghouse is developing three-dimensional radar equipment for the Air Force's Hawkeye (Saint) inspection-satellite program.

• Radiation Inc. received the NASA contract to furnish the PCM telemetry system for the Nimbus polar-orbit weather satellite.

• Page Communications Engineers Inc. awarded Dynamics Corp. of America's Radio Engineering Laboratories its first space contract—the building of a 10,000-w FM transmitting station that will be used to bounce messages between Floyd, N.Y., and Trinidad in the Air Force passive communications satellite program.

DEFENSE DEPARTMENT

• Army and Navy space aspirations were dashed by Defense Secretary Robert McNamara in a directive assigning the Air Force almost total responsibility for future space systems. The Army and Navy will be allowed limited funds for preliminary research to develop requirements for new space systems; but once these proposals are approved, development, test, and evaluation will automatically be conducted by the Air Force except under "unusual circumstances," McNamara ruled. He said that assignment of operational responsibility will be made on a case-by-case basis, leaving the door open for possible Army and Navy participation; and he exempted the Army's Advent communications satellite and the Navy's Transit navigation satellite from the new directive. But it was clear that the Air Force had triumphed in its campaign to become the nation's military space agency.

• Military spending in fiscal 1962 may climb \$2.1 billion—to a total of \$45 billion—as a result of increases proposed by Secretary McNamara's

study groups. In the strategic area, the panel headed by Pentagon Comptroller Charles J. Hitch recommended boosting from one-third to one-half the proportion of SAC bombers maintained on 15-min runway alert, and it called for a continuous airborne alert by 30 B-52 bombers instead of the 12 planned by the Eisenhower administration.

• Accelerated construction of Atlas and Titan ICBM sites and a second plant for the Minuteman solid-fuel motors was recommended, but the panel did not call for a doubling of Minuteman production, nor increased Polaris submarine construction.

• In the tactical area, the McNamara study groups proposed an increase in total military manpower and greater emphasis on light, mobile weapons for the Army. In the development area, the group headed by Defense Research Director Herbert York called for continued effort on the Skybolt air-launched ballistic missile and the B-70 Mach 3 bomber and acceleration of 2500-mi Polaris A-3 missile. No recommendation was made for limited production of the Nike-Zeus, despite powerful Army pressure to commence production of long lead-time computer and radar components in advance of tests of the anti-ICBM weapon scheduled next year in the Pacific against Atlas warheads to be fired from Vandenberg AFB.

• The Army Corps of Engineers negotiated a \$61.8-million contract for construction of 150 Minuteman silos and 15 underground control centers at Malmstrom AFB, Mont. The cost was more than 23% higher than target price of \$50 million, but well below the initial low bid of \$78 million. The latter was thrown out, and a new round of bids was solicited on a modified fixed price contract in which some penalty provisions were eliminated. The Malmstrom job was awarded to a joint venture established by the George A. Fuller Co. and the Dell E. Webb Construction Co.

• The Navy awarded Raytheon Co. a \$28.2-million follow-on contract for production of the all-weather Sparrow III air-to-air missile. It gave Grumman Aircraft Engineering Corp., Bethpage, N.Y., a \$38 million contract for continued production of W2F-1 early-warning and intercept aircraft, bringing the total for this project to \$179 million.



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Another Way Grove Sets Regulator Standards for Others to Follow

- The Air Force announced an \$8.5-million program to build a hardened underground combat center for the North American Air Defense Command that will eventually replace the "soft" control system at Colorado Springs.

SOVIET VENUS PROBE— LESSON IN ASTRONAUTICS

- Although the Russians made the favorable Venus transit date for a probe early this year, the torrent of high-powered hoopla over the 1418-lb Venus spacecraft suddenly dropped to a whisper when it refused to respond to ground commands after 15 days on its Venus trajectory. The spacecraft at this time was about 3 million miles from earth, on a path intended to bring it closest to Venus about May 20. The malfunction left the U.S. with the honors for long-distance space communications: The 95-lb Pioneer V survived 107 days after its launching a year ago and transmitted its data on command over a distance of 22.5 million miles.

- Moral: Communications will measure the success of deep-space ventures.

- In deference to the Soviet effort, the attitude-controlled Venus probe represented a new order of spacecraft complexity compared, for instance, with the nonstabilized, omnidirectional Pioneer V. A failure in the system designed to slave its command-receiver antenna to the earth would prevent it from receiving command instructions and reading-out data. Significantly, the Russian Venus shot is generally similar to the Mariner series of interplanetary "fly-by" spacecraft now under development by NASA's Jet Propulsion Laboratory. Two of these 1150-lb packages are to be readied for Atlas-Centaur launch on Venus trajectories in August 1962, when the next "window" is available, according to NASA Deputy Administrator Hugh Dryden.

- The Soviet Venus attempt threw considerable light on Russian space activity for the past several months. It seemed almost certain that the 7-ton satellite launched 8 days earlier was a duplicate Venus shot which failed to respond to commands from the Pacific tracking ships to leave its parking orbit and enter a Venus trajectory. There

was also speculation in top government quarters that the Russians attempted a Mars transit last fall (when the tracking ships were in the Pacific) but that they were hamstrung by malfunctions at that time, also. (One top-level Administration official suggests that Khrushchev's table-pounding at the United Nations meeting last fall was a reaction of dismay over the Mars-probe failure rather than anger with the U.S. over the U-2 incident.)

- The day before contact was lost with the probe, the Russians issued detailed information on its instrumentation, power supply, and control system. They said the spacecraft carried four antennas (probably including radar and radiometer for Venus measurements), magnetometers, micrometeorite experiments, and energetic-particle counters. Nothing was said about an optical camera system, and probably none was included. Power came from two solar-cell panels feeding chemical batteries. It was expected to transmit data on command every 5 days at a frequency of 922.8 mc. The Russians did not disclose their interrogation schedule nor a sufficiently tight fix in space to enable the 250-ft Jodrell Bank radio telescope to detect its signal. They said the probe should come within 62,000 mi of Venus, probably close enough to detect the presence of a magnetic field and radiation belts.

- The Russian space feat set off a new round of speculation over the nature of the Soviet space booster. Kraft Ehricke, director of Convair Astronautics' Centaur program, believes that the Russians doubled the thrust of their first-stage booster since the Lunik series was completed in 1959, thus enabling them to orbit 5-ton spacecraft and 7-ton platforms for launching Venus probes. He suggested to Congress that the "workhorse" Russian engine is a unit of 440,000-lb thrust (an old Peene-munde project) and that the Russians teamed a pair of these together in the Pacific tests conducted more than a year ago.

- On the other hand, NASA's Deputy Hugh Dryden believes that the Russians have used a first-stage booster of 800,000-lb thrust throughout their entire space program and that payload growth has been accomplished by adding a third stage and improving the ex-

isting second stage. According to this line of reasoning, the Sputnik and Lunik flights might have been conducted by the unsophisticated two-stage version, and the later shots may have been boosted by the souped-up three-stage rocket system.

1963 SPACE COMMUNICATIONS

- The governments of many nations are actively engaged in preparation for the 1963 Extraordinary Administrative Radio Conference on Space Communications. The 1963 conference was scheduled during the 1959 World Conference of the International Telecommunication Union at Geneva. The ITU recognized then that frequency allocations for space research agreed on at the 1959 conference were but a first effort to provide spectrum space for the astronautical programs of the various nations. The new conference will consider much broader and more refined proposals for the use of radio in space flight. Much greater demands for spectrum space must then be met.

The U.S. is presently formulating its position in anticipation of the 1963 Conference. The Federal Communications Commission instituted a special public inquiry into the astronautical radio spectrum requirements in May 1960. In December 1960 the FCC broadened its inquiry so as to focus attention on the critical problem of sharing space radio frequencies with earth users. The inquiry is also concerned with determining criteria for the establishment of earth terminals for space communications systems, and will consider proposals for the setting aside of large terminal areas free from earthbound radio users [familiar to the regions set aside for radio astronomy use].

THE LOW ROAD

- Addressing itself and industry to problems of reliability and cost of space vehicles and launch operations, NASA has called for "an entirely new philosophy of how to design, manufacture, test, and launch our vehicles." This was the keynote of an important statement by NASA Assistant Administrator for Programs W. A. Fleming at the recent ARS testing conference in Los Angeles. No more than 6 days for the vehicle at the launch site is the goal envisioned by him. ♦♦



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For the record

The month's news in review

- Feb. 1**—Three-stage Minuteman ICBM with full guidance system soars 4200 mi down Atlantic in successful test shot by Air Force of first complete unit.
- Feb. 2**—Senate space committee approves selection of James W. Webb to be new head of NASA.
- Feb. 4**—USSR hurls 7.1-ton Sputnik V, heaviest object yet, into orbit around the earth.
—Yugoslavia announces plans to launch a sounding rocket, a Japanese-made Kappa-6, within a year.
- Feb. 5**—NASA-Wallops fires Aerobee-Hi to test behavior of liquid hydrogen under zero-gravity conditions.
- Feb. 7**—X-15 is piloted to record 2275 mph by Maj. Robert White.
- Feb. 9**—Smithsonian Astrophysical Observatory reports that new calculations show earth is a slight irregular ellipsoid.
- Feb. 10**—AF fires Titan 5000 mi over Atlantic in 30 min.
- Feb. 12**—USSR sends 1418.66-lb instrumented space rocket toward Venus from Sputnik launching vehicle orbiting earth.
- Feb. 13**—AF successfully test fires GAM83B, new air-to-surface missile.
- Feb. 15**—President Kennedy reporting on space-lag controversy says U.S. is behind USSR in space boosters, but U.S. rocket engines are adequate for defense purposes.
- Feb. 16**—NASA solid-fuel four-stage Scout launching vehicle performs excellently in first test and places 12-ft balloon satellite, Explorer IX, into orbit.
- Feb. 17**—AF launches into orbit Discoverer XX, slated to eject 300-lb recoverable capsule upon ground command.
- Feb. 18**—AF puts Discoverer XXI into orbit and restarts Agena engine on satellite's first polar orbit.
- Feb. 20**—Navy proposes use of Polaris as a mobile satellite launcher.
- Feb. 21**—NASA chooses three astronauts—John H. Glenn Jr., Virgil I. Grissom, and Alan B. Shepard Jr.—to begin special training for first U.S.-manned space flight.
—AF Thor-Able-Star rocket lifts Transit III-B and a "hitchhiker" vehicle, Lofti, into orbit, but satellites fail to separate.
- Feb. 22**—French recover Hector alive, an encapsulated rat shot to 95-mi altitude over Sahara desert by a Veronique missile.
- Feb. 25**—NASA study says USSR is lagging far behind U.S. in space research despite Soviet Union's "great achievements in space technology."
- Feb. 28**—NASA makes public "memorandum of understanding" with FCC on private communications satellites development and changes in radio frequency specifications.

International scene

By Andrew G. Haley

THE International Astronautical Federation meetings held in Paris on March 2-7, 1961, were distinguished by remarkable agreement and spirit of cooperation between the member societies from the USSR, the Eastern European nations, the Western European nations, and the societies from the Western Hemisphere.

The Committee on the Revision of the Constitution—composed of Vladimir Kopal, chairman, William H. Pickering, L. R. Shepherd, E. A. Brun, L. I. Sedov, and Andrew G. Haley—met for several hours on Thursday, March 2, and thoroughly considered the new draft of the Constitution pro-

posed by Dr. Kopal. On the first reading, procedural questions were fully disposed of and a large number of substantive matters were decided upon. The next day, the Committee met at an early hour of the morning and worked for several hours, the members at all times earnestly seeking the resolution of all problems without undue compromise. The United States delegation was supplemented by the presence of Howard S. Seifert, and other officials were invited to attend, including Michel Smirnoff of Yugoslavia.

By common agreement it was decided to eliminate any positive require-

ment with respect to the necessity of electing officers from the USSR and U.S.A.; and, in lieu thereof, in Article 25 of the Constitution "policy" language was adopted, as follows: "In the election of officers due regard shall be specially paid to candidates of Members from those countries where astronautics has reached a high degree of development and to the necessity of equitable geographical distribution." It must be observed that this statement does not tie the hands of the General Assembly, but simply declares policy which would be adhered to, as a matter of common sense, in any event, and which also takes into considera-

tion the best interests of small and distant countries.

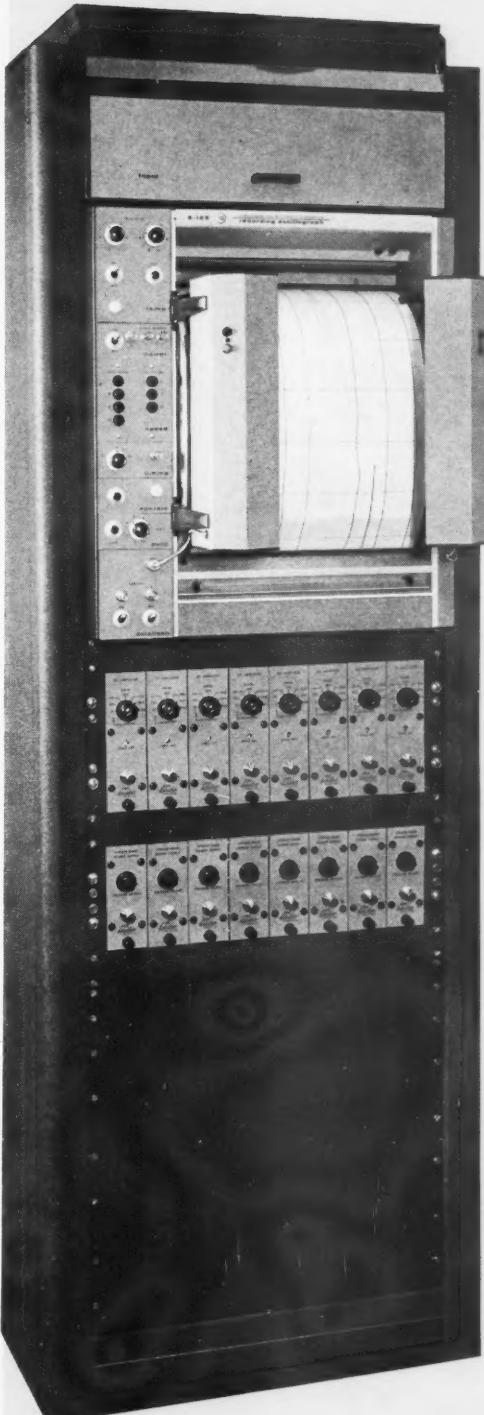
The powers of the General Assembly were in no way curtailed, although under Article 35 the Bureau has the duty to prepare and submit an agenda for the Congresses of the IAF; nevertheless, under Article 19 the General Assembly has the power "To approve and modify the Agenda of its plenary meetings proposed and submitted by the Bureau." All members of the Committee recognize the necessity of avoiding the impact of demagoguery and thoughtlessness which so often threatens plenary sessions of parliamentary bodies, so it was unanimously decided that while modifications in the agenda could be required by the General Assembly, the changes desired should be given interim consideration by the Bureau. This provision was inserted as a "stop-gap" against hasty actions, but the provision does not ultimately restrain the sovereign powers of the General Assembly. Furthermore, in the conduct of the business of the Bureau, procedural matters may be decided informally, but matters of serious substance must receive unanimous approval. For example, if in arriving at a budgetary decision any undue financial burden might be suggested to be placed upon members from small nations, such members would have the right, through representation on the Bureau, to demand unanimous agreement on the final decision of the Bureau. In other words, the small Society has the same right to request unanimity on a substantive matter as has the large Society. No distinction is made with respect to the USSR or the U.S.A.

The Bureau adopted a memorial thanking the Colombiano Institute of the City of Genoa, Italy, for the \$8000 Christopher Columbus Award, stating, "In accepting this award, we are encouraged to follow the spirit of the great explorer Columbus in our efforts to foster cooperation between all nations in opening the new frontiers of space. On behalf of the General Assembly of the International Astronautical Federation, the undersigned members of the Bureau express their sincere appreciation of the generous gesture of the Colombiano Institute."

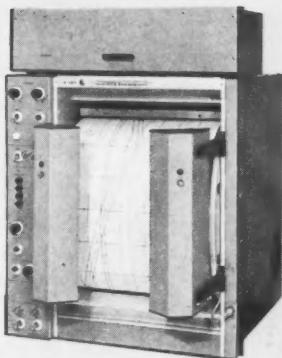
Attending the meeting of the Bureau were E. A. Brun, W. Buedeler, Haley, Kopal, W. G. Kostomarov, F. J. Malina, J. Peres, R. Pesek, Pickering, Sedov, Seifert, Shepherd, Smirnoff, and T. von Karman.

The French National Bank entertained all the delegates at a reception on March 3. On March 4, the Ministry of Foreign Affairs entertained the

(CONTINUED ON PAGE 95)



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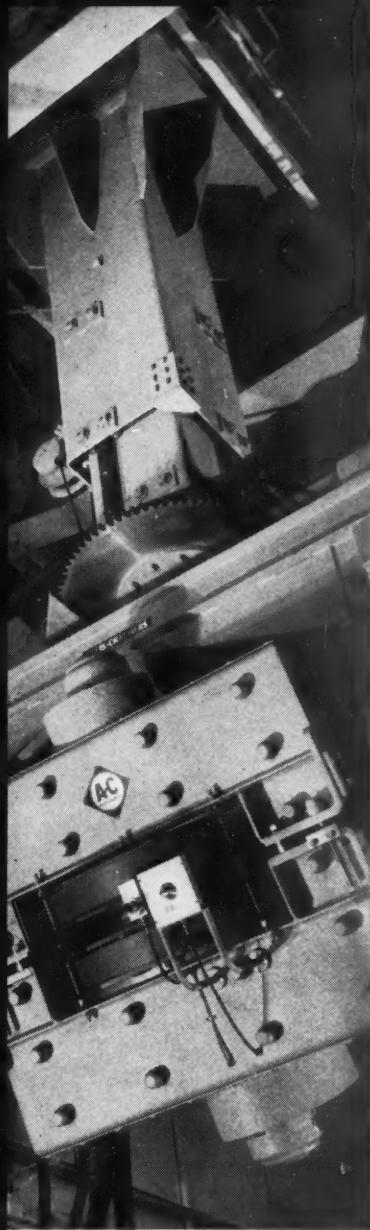
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Within these labyrinthined entrances, shielded from the world by six feet of reinforced concrete and full-height earth barricades, lurks the mighty Betatron. Its task: to search out any defect in production-line propellant grains exposed to its powerful X-ray eye.

This giant eye is only one part of our complete nondestructive test installation at Bacchus. Through such steps, the life history of each individual unit becomes an open book—its reliability can be computed, its readiness known before the need arises. Such exacting tests pave the way to space.

Vastly more powerful than any known industrial X-ray apparatus, the Betatron yields a clear picture through the full girth of the third-stage Minuteman engine in an eight-minute exposure, contrasted with more than a nine-hour exposure required with 1,000 curies of cobalt 60. Resolution is such that irregularities down to 0.01 inch can be examined. Power of the instrument, and dimensioning of the building which houses it, are more than equal to the task of scrutinizing interior topography of the cast composite double-base solid-propellant motors made at Bacchus: the third-stage Minuteman, advanced second-stage Polaris, Altair, and the others.

XP61-1

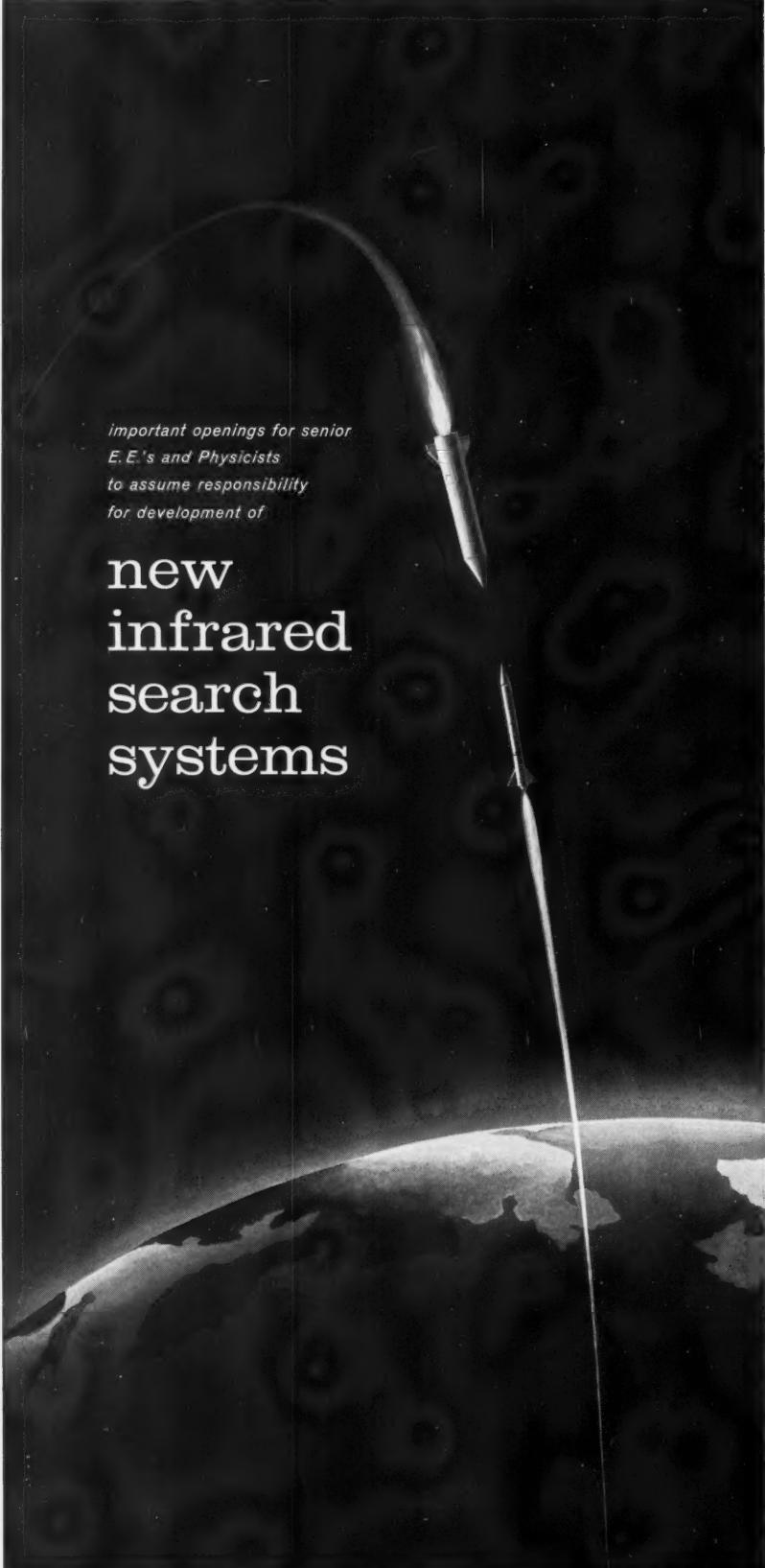


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-
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 - 3. Air-To-Air Detection Search Sets**
 - 4. Satellite Detection & Identification**
 - 5. Infrared Range Measurement**
 - 6. Detection Cryogenics**
 - 7. Detector Application Physics**
 - 8. Optical Systems Design**
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Integration: A Problem for ARS Too

IT SURPRISES a lot of the 18,000 ARS members today to learn that their Society was called the American Interplanetary Society when it was founded in 1930.

In 1934 the name was changed to AMERICAN ROCKET SOCIETY because, as *Astronautics* of March 1934 explains, "in the opinion of many members, adoption of the more conservative name, while in no way implying that we had abandoned the interplanetary idea, would attract able members repelled by the present name."

For years, the big problem for the adherents of space flight in ARS was the development of the rocket engine, and so the Society and its JOURNAL concentrated on propulsion. There was no desire to exclude other disciplines necessary to the development of a space technology. The other disciplines simply hadn't gotten started yet. They all had to wait for the rocket.

Nevertheless, the JOURNAL didn't restrict itself entirely to propulsion by a long shot. For example, here are some titles of articles published more than 10 years ago—in 1951 issues: "Interplanetary Travel Between Satellite Orbits," by L. Spitzer Jr.; "Automatic Navigation of a Long-Range Rocket Vehicle," by H. S. Tsien, T. C. Adamson, and E. L. Knuth; "Manned Flight at the Borders of Space," by H. Haber; "Exposure Hazard from Cosmic Radiation at Extreme Altitude and in Free Space," by H. J. Schaefer.

It's safe to say, though, that of the 1000 members in 1951 not more than a few hundred were in fields other than rocket propulsion.

Now, 10 years later, we take another look at the Society. A breakdown recently made of a 1000-member sample shows that propulsion is no longer even the No. 1 field represented. The sample shows that 26.4% of our members are in the "Vehicles and Vehicle Systems" category, 18.2% in "Propulsion," 16.1% in "Guidance, Control, Communications, and Instrumentation," and lesser percentages in other fields.

Further, of the 273 members of the 19 ARS Technical Committees, 184 deal with the 12 Committees that have nothing to do with propulsion—Astrodynamics; Communications and Instrumentation; Guidance and Navigation; Human Factors and Bioastronautics; Hypersonics; Missiles and Space Vehicles; Physics of the Atmosphere and Space; Power Systems; Magnetohydrodynamics; Space Law and Sociology; Structures and Materials; and Test, Operations, and Support. At the 15th Annual Meeting in Washington, 115 of the 165 papers presented were on these subjects.

This is as it should be. The ARS problem is not simply whether we have the capability to send a 100,000-lb payload into space—it is to *integrate* the problems of a whole gamut of fields represented by the spheres of interest of the Technical Committees into answers which add to the over-all space flight capability of the U.S. and the world.

This was our objective in 1930. It remains our objective in 1961.

Harold W. Ritchey
President, AMERICAN ROCKET SOCIETY

Rendezvous in space

For the great missions, man's exploration of the moon and planets, true spaceships will be necessary, and we must choose soon the means to make these a reality

By Kurt R. Stehling

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, WASHINGTON, D.C.

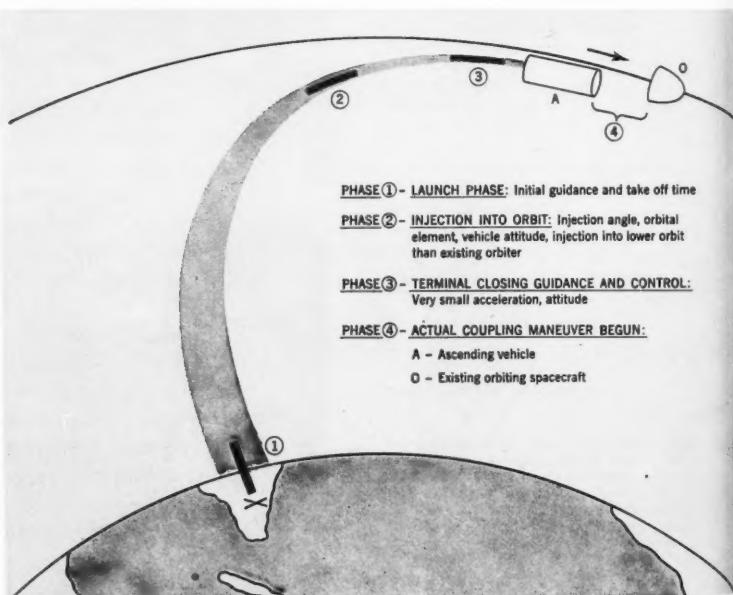


Kurt R. Stehling is a staff scientist in NASA's Office of Program Planning and Evaluation for the Administrator. He was formerly head of the Vanguard Propulsion Group at NRL, charged with supervision of power-plant development for the project. A graduate of the Univ. of Toronto, he did work on high-altitude infrared spectrometry and combustion phenomena while with the American Optical Co. in 1949-50; was a rocket research engineer with Bell Aircraft from 1950 to 1953; did research at Princeton's Forrestal Research Center in 1953-54; and was acting group leader of Bell's Fluid Mechanics and Heat Transfer Rocket Section prior to joining NRL in 1955, moving to NASA when the Vanguard project came under the agency's direction.

The opinions expressed in this article, the author notes, are his own and do not necessarily reflect official views of NASA.

PROPULSION energy and propulsion energy alone can project a spacecraft into space. The heavier the spacecraft, the more propulsion energy required—there can be no equivocation with this simple fact. As our space missions become more complicated and ambitious, our spacecraft will become heavier. As the spacecraft become heavier, the vehicles will have to become larger. We can increase their energy content per given volume—that is, increase the specific impulse of the propulsion systems—and thus stave off temporarily some of the inevitable increases in vehicle size. But for any given vehicle propulsion system there is an almost direct relationship between the weight of a spacecraft and the size of the booster needed.

It should be obvious that as spacecraft achieve very large sizes and weights, boosters may reach a point where they become inordinately large. This growth factor is paralleled by other forms of transportation vehicles, such as ships and aircraft. These have



reached, or are reaching, the point where size has distinct limitations, and other stratagems are necessary to overcome the drawbacks of very large dimensions.

In astronautics, size limitations are even more painful. At our present stage of space development, for instance, the cost of developing a new set of vehicles for each new and larger space objective becomes tremendous.

Workers in the field have recognized this for many years. As far back as the late 1920's, such men as von Pirquet, Oberth, and others in Europe, and, since the last war, von Braun, Kraft Ehricke, and some of their colleagues and other American scientists, and Russians for that matter, have reviewed the problems of large vehicle construction and have concluded in many cases that some form of "incremental" space flight should be established.

The names given this stratagem include "orbital rendezvous" or "orbital interception" or "refueling in space," etc. Whatever the name of the scheme, it embodies some form of refueling of a spacecraft. Its aim is to set a limit on the building of larger and larger rocket vehicles and permit some terminal size that has the capability of launching large spacecraft, with a good reliability and the capability of establishing contact in space and adding to the final spacecraft, by increments, the extra propulsion energy and other supplies needed for a deep-space journey.

This problem of rendezvous vs. large "one shot" boosters is facing the entire area of space flight today. Some very important decisions will have to be made in the next two or three years on the

desirability of undertaking the development of very large rocket engines that may power colossal first-stage boosters for such missions as manned lunar landings and permanent space stations. Alternatively, the question must be answered: Can a medium-sized booster be developed with a high efficiency and reliability and be usable for rendezvous schemes that will do in the end what would "normally" be done with large single vehicles?

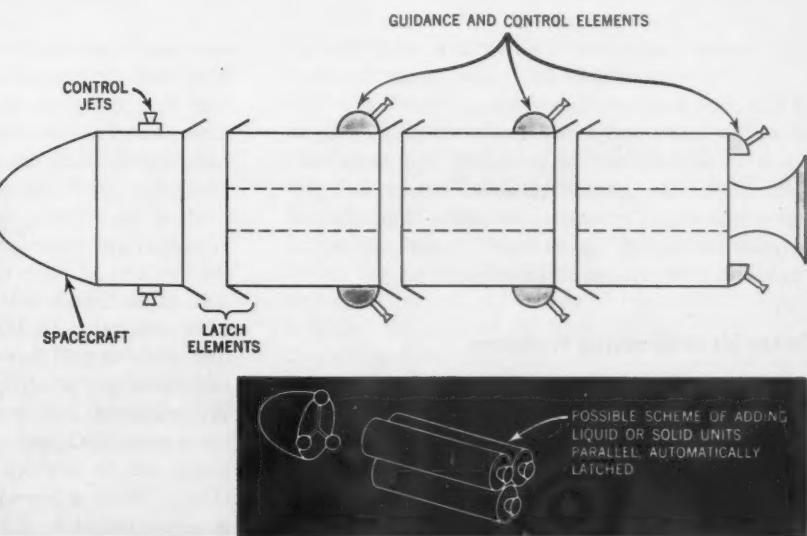
Problems Confronting Engineers

Even without discussing particular space flight missions that might demand boosters beyond presently available or planned ones, or that might demand rendezvous, it is of value to review briefly some technical problems that confront astronautical engineers who favor rendezvous projects.

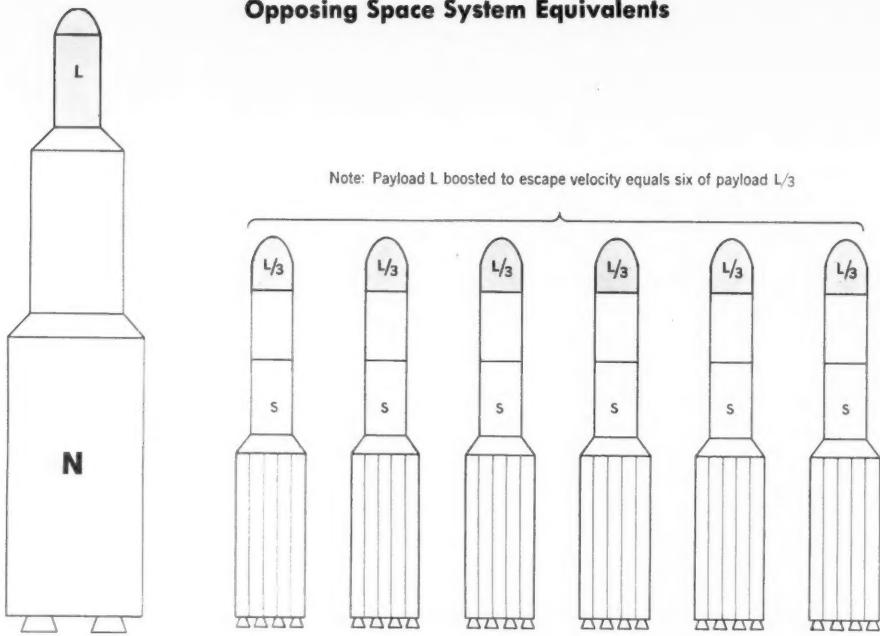
The space rendezvous maneuver for refueling looks similar in some ways, superficially similar, to aerial refueling of jet bombers. Refueling is treated here as a major purpose of rendezvous for simplicity; there are other important ones—crew exchange, provision of stores, etc.

Interestingly enough, aerial refueling can actually be a more difficult technical problem in some respects than orbital refueling. Two aircraft must first of all find each other in a large expanse of aerial territory and then approach closely and transfer large quantities of inflammable liquids. Very close coordination must take place between the two aircraft crews, yet much of the fuel transfer must be done automatically without the actual coupling be-

The sketches depict adding of propulsion-system packages in series or parallel. Control of the operation might be entirely from the spacecraft, rather than chiefly from the ground, in an advanced system.



Opposing Space System Equivalents



The huge N vehicle for a direct flight to escape velocity equates roughly to six S vehicles taking L/3 payloads to orbital velocity and then subsequent orbital launch of an assembled L payload to escape.

Estimated Economics of the Two Systems

VEHICLE N

- N costs to reach operation, including launch facilities, at 90% reliability.....\$6 billion
- Cost per launch of N with payload.....\$100 million
- Cost of 100-payload mission contemplated, requiring 100 N launches.....\$10 billion

N: Total mission cost... \$16 billion

VEHICLE S

- S costs to reach operation, including launch facilities, at 90% reliability.....\$1 billion
- Cost per launch of S with payload.....\$15 million
- Cost of mission equivalent to 100 N, requiring 600 S launches.....\$9 billion
- Cost to develop rendezvous technique.....\$1 billion

S: Total mission cost... \$11 billion

Note: Time would be a more weighty factor in the N System development.

Cost of operational failures with the two systems are assumed equal.

ing done by the crews. The air is an impediment, since a crewman cannot just walk out on the wing or tail of a bomber and plug in a gasoline hose. The air stream and aerodynamic forces not only preclude much crew handling of refueling equipment but also subject the aircraft to disturbances and perturbations which greatly increase the difficulties of a quick mating of the aircraft, to say nothing of such side problems as possible collision.

Other Heartbreaking Problems

If refueling is done in space, there are no aerodynamic forces. No, there are other heartbreaking problems, which might be summarized briefly as follows.

First, let's look at problems of mechanically

coupling hoses or pipes. The propellant or propellants that are needed by the earth-escaping spacecraft have to be transferred under weightless conditions in an environment of intense solar, and other, radiations. This inimical environment probably precludes much servicing manipulation by astronauts in an orbiting craft. Suppose our two space vehicles have approached closely enough to permit the coupling of pipes to tanks. Then what? Under zero-G the liquids will have no "head" and will have to be fed either by bladder or piston tanks, or the two vehicles will have to have some small ullage rockets or gas jets to produce a small acceleration. The slightest leak with cryogenic propellants, if these were used, and at the high pressure ratios existing, would produce a great cosmic steam-kettle effect. With a bipropellant rocket (instead of a monopropellant or a nu- (CONTINUED ON PAGE 46)

IAS-ARS joint meeting set

The country's two largest societies representing aeronautical and astronautical science and engineering join hands in June for history-making joint meeting on the West Coast

A TENTATIVE program of more than 110 technical papers has been established for the National IAS-ARS Joint Meeting scheduled for June 13-16 at the Ambassador Hotel in Los Angeles, Calif.

This marks the first time that the two largest American professional societies concerned with aeronautics and space technology have held a major joint meeting. The occasion will combine the traditional ARS Semi-Annual Meeting and the IAS Summer Meeting.

The joint meeting will be the largest technical conference held on the West Coast this year, and the only major interdisciplinary meeting either society will hold on the West Coast this year.

Some 32 sessions have been scheduled for the joint meeting, covering a broad range of technology, from VTOL aircraft to deep-space vehicles.

The program has been organized under the direction of Charles W. Eyes of Norair Div., Northrop Corp., in conjunction with program vice-chairman Chauncey J. Hamlin Jr., of North American Aviation.

The program has been arranged to provide quadruple concurrent sessions in the morning, afternoon, and evening. A banquet and dance at the Coconut Grove has been scheduled for Thursday evening, June 15th.

NOTS Program Planned

A special program has been planned for Friday, June 16th, by the ARS Underwater Propulsion Committee at the Naval Ordnance Test Station, Pasadena, Calif. A review of the developments in underwater propulsion at NOTS is planned. Security arrangements for

the trip will be announced.

Of primary interest to the ARS members attending the conference are the sessions devoted to astrodynamics, earth-landing and re-entry problems, major missile progress reports, and military applications of space vehicles.

In addition, there will be sessions on electrical propulsion, digital-computer applications, structures and materials, planning for success in the one-shot mission, communications and instrumentation, communication-satellite systems, space operations and maintenance, space physiology and performance, and orbital aircraft.

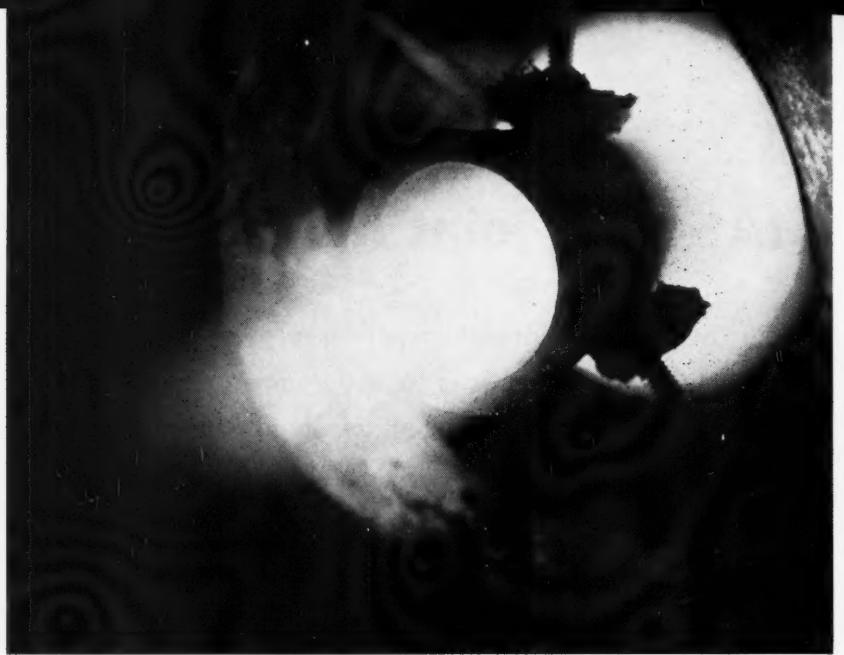
Space Papers Featured

Some of the papers to be presented at the meeting which will receive special attention from ARS members include "Current and Possible Future Air Force Programs" in the Military Applications of Space Vehicles session, and "NASA Program in Communication Satellites Systems," which will be presented in the Communications and Instrumentation session.

A paper on "Some Thermodynamic Problems of Orbital Aircraft" will be presented in the Orbital Aircraft session, and the Space Physiology and Performance session will feature a paper on "Interdependence of Radiation Shielding and Satellite Design."

Sessions that will be classified are: Program Status Report on Titan ICBM, Advanced Air-breathing Propulsion Systems, Orbital Aircraft, Military Applications of Space Vehicles, and Liquid Rockets.

Security arrangements will be handled through the AF Air Research Development Command. In out- (CONTINUED ON PAGE 77)



Applications of materials to solid-rocket nozzles

The ever-increasing performance of propellants, headed for combustion temperature of 8300 F in the next decade, stimulates the drive for better nozzle materials, better known and more cleverly applied



Edward W. Ungar, is a principal mechanical engineer at Battelle Memorial Institute, where he has been engaged in studies related to high-temperature environments, ablation pressures, fluid dynamics, and nozzle development since joining the well-known institution in 1957, after receiving a degree in mechanical engineering from the City College of New York. He received an M.Sc. from Ohio State Univ. in 1959. His previous publications have been related to combustion-system modeling and particle impacts on ablating surfaces.

By Edward W. Ungar

BATTELLE MEMORIAL INSTITUTE, COLUMBUS, OHIO

SOLID-propellant rocket engines offer distinct advantages over liquid-propellant engines, particularly simplicity and constant readiness. However, one disadvantage is that the solid rocket's fuel cannot be used directly to cool the exhaust nozzle, as is done commonly in liquid engines. The solid-rocket nozzle must either be capable of operation in the environment produced by the combustion product or some type of a built-in thermal-protection system must be used.

The conventional bell nozzle is the type which is currently used most widely. It is a fixed-geometry device which has a fixed expansion ratio and thus, with a fixed combustion pressure, has the optimum shape at only one altitude. Advanced nozzle concepts, such as the plug nozzle¹⁻³ and the expansion-deflection nozzle,⁴ which are being studied, offer the advantage of altitude compensation. (Superscript numbers indicate references at the end of the article.)

The design of minimum-weight nozzles for solid rockets has become increasingly difficult, because of increases in burning times and the introduction of propellants with higher and higher performances.

Burning time is a critical factor because the nozzle must maintain its integrity while exposed to exhaust products as long as an engine operates. Propellants currently being developed produce exhaust products with higher temperatures and greater chemical activity than those used previously. In addition, these products of combustion often carry a high concentration of particles in suspension.

In view of these trends, our purpose here is to identify problems involved in both the selection of materials and the development of nozzles for use in solid-propellant rocket engines, and also to examine approaches being taken to solve these problems.

Structural Design Concepts

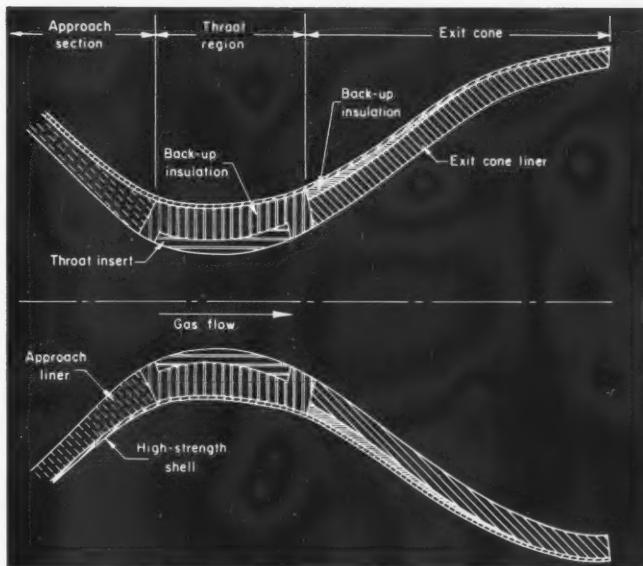
The environment produced by the combustion of a solid propellant imposes restrictions on the selection of materials for use in uncooled exhaust nozzles. These restrictions are in addition to those normally associated with selecting materials for flight vehicles. Let us approach the materials-selection problem by a brief description of the hypothetically ideal material.

An ideal material must operate for extended periods essentially at equilibrium with the hot combustion products. The material must therefore (1) be sufficiently refractory to withstand the maximum combustion temperatures contemplated, while retaining a reasonable strength, (2) be chemically compatible with combustion products, (3) be resistant to both thermal and mechanical shock, (4) be sufficiently tough to withstand mechanical abrasion resulting from high-velocity particle impacts, (5) have a high strength-weight ratio, (6) be ductile, (7) be readily available and present no serious fabrication difficulties, and (8) have reasonable cost.

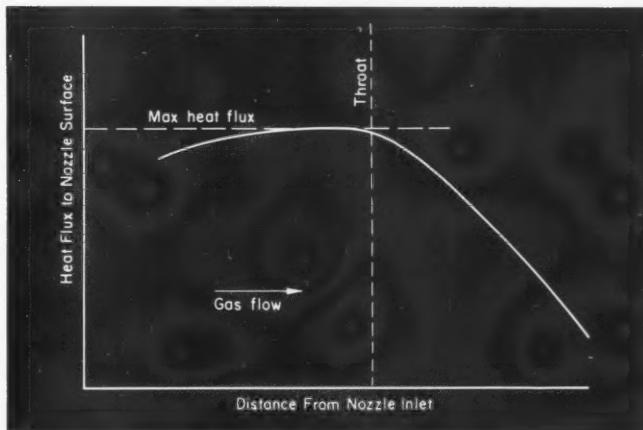
Unfortunately, this ideal material does not exist and probably will not be available in the foreseeable future. Therefore, schemes are required which allow the use of materials of lesser potential. These schemes involve the use of several materials in a composite structure that utilizes the desirable properties of each.⁵ The effects produced by undesirable properties (such as high density) must be minimized in the design of the composite structure. A composite-nozzle structure is illustrated schematically on this page.

Hot Structures. A "hot" structure is one which operates continuously with exposed surfaces so hot as to be almost adiabatic. Materials for the exposed element of a hot structure must possess at least the first three properties of the ideal material. The supporting materials of the composite structure must compensate for deficiencies in the other properties listed. Low thermal conductivity thus becomes desirable, to prevent overheating of the less

Modified Hot-Structure Type of Nozzle



Heat-Flux Distribution in a Nozzle



refractory components in the composite.

There are advantages in the use of hot structures, and also certain difficulties involved in attaining such a system in practice. The principal advantages are reproducibility of engine performance and possibility of a minimum-weight design.

Heat-Sink Structures. The heat-sink concept is based on the assumption that a structure which would ultimately fail or melt in a severe thermal environment may perform satisfactorily while it is being heated. Thus, for a finite time after introduction into the environment, the structure is satisfactory, but failure by melting or loss of strength will result from exposure for longer periods of time.

To extend the time of satisfactory operation, the material must be capable of rapidly transferring this

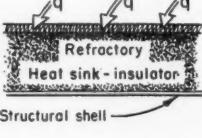
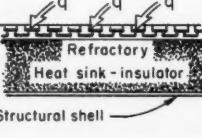
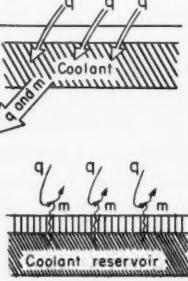
heat impulse into the interior of the structure. That is, the material must possess a high thermal conductivity. When the mass of the structure must be minimized for a particular total energy absorption, the product of specific heat and available temperature range as a solid must be large. When rate of absorbing heat becomes the dominant requirement, the thermal diffusivity is the more important material property.

In practice, composite nozzle structures can be used that employ highly refractory materials on the exposed surface, but also have an appreciable heat-sink capacity in the underlying material. The ex-

posed surface layer is thus cooled by the underlying materials sufficiently to delay surface melting or appreciable loss in strength beyond the required operating time. These structures might be termed "modified hot structures."

Ablative Structures. Ablation systems have been studied extensively in connection with the re-entry problem. The ablation process consists of the formation of relatively cool gas and/or liquid melt-layer by decomposition, melting, sublimation, or melting, with subsequent boiling. A good general discussion of this subject, pertinent to nozzle design, was recently pre- (CONTINUED ON PAGE 83)

Nozzle Environments and Philosophies

Time Period	1960-1965	1965-1970	1970-1975
Representative flame temp, F	6300	7000	8300
Estimated heat flux to throat, Btu per sq-in.-sec (at 600 psi)	~30	~35	~60
Chemistry of exhaust products	Dissociated, generally reducing	Dissociated, generally reducing	Highly dissociated, fluorine may be present
Non-gaseous exhaust species	Primarily aluminum oxide	Depending on propellant: oxides of aluminum lithium beryllium magnesium	Depending on propellant: oxides of lithium beryllium magnesium
Available basic materials for equilibrium operation	Tungsten, some carbides	Some carbides, nitrides, and borides	None
Pertinent design philosophy for throat region in composite nozzle structure	Modified hot structure 	Modified hot structure 	Cooled structure 

Composite ceramic-metal systems

Under development for service at temperatures of 3000-6000 F, for a variety of space-vehicle applications, they represent a shift of materials engineering from raw producer to specialist

By A. V. Levy, AEROJET-GENERAL CORP., SACRAMENTO, CALIF.

S. R. Locke, MARTIN CO., ORLANDO, FLA.

H. Leggett, HUGHES TOOL CO., CULVER CITY, CALIF.

THE ADVENT of the aerospace age has presented new and difficult requirements to materials producers, requirements that are as much of a revolution in the materials field as is the whole aerospace technology now being generated. The decrease in quantity and increase in quality and specialized performance of products demanded of materials producers promises to alter the previously established pattern of materials utilization by the aerospace industry. In the future, the materials user, and not the producer, will create from raw materials specialized materials that he will subsequently form to the required shapes. The small quantity of materials needed and the unique performance required of them will force the user to create the material as an integral part of a system program, rather than obtain it from the materials producer in a form that is ready to be molded to shape.

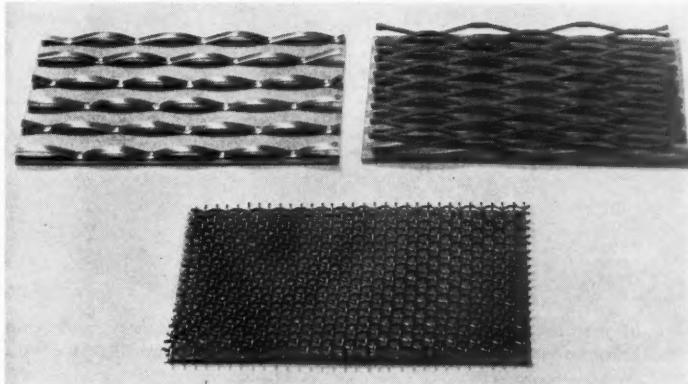
Probably the foremost example of materials that will follow this path of development and utilization are the composite ceramic-metal systems. The successful development of material systems to withstand the severe environments of re-entry components, solid-rocket nozzles, uncooled liquid-rocket chambers, electrical-propulsion components, and other aerospace devices that will operate

Alan V. Levy is head of the Materials Research and Development Dept. in Aerojet-General's Solid Rocket Plant. A graduate of the Univ. of California with an M.S. in physical metallurgy in 1951, he started his career with Marquardt as head of its materials and process engineering activity, responsible for all of the materials and fabrication development required to produce advanced ramjet engines; continued his career at the Hughes Tool's Aircraft Div., where he was manager of the Materials Engineering Dept., specializing in the development of high-temperature components, such as solid-rocket nozzles; and recently joined Aerojet to direct the materials engineering activity associated with solid rocket motor development.

Saul R. Locke recently joined Martin-Orlando, where he will be responsible for materials engineering work. Prior to this assignment he spent several years with Aerojet-General and Hughes Tool working in the field of advanced material systems for uncooled solid rocket motor nozzles. He graduated from the Polytechnic Institute of Brooklyn with an M.S. in metallurgical engineering in 1954.

Hyman Leggett is manager of the Materials Engineering Dept. at Hughes Tool's Aircraft Div., in charge of development work on ceramic composite systems for uncooled rocket nozzles. Prior to joining Hughes Tool, he was responsible for ceramics-development programs at Marquardt and Rocketdyne. He received a B.S. in ceramic engineering in 1942 from the Missouri School of Mines.

Examples of Metal Reinforcements



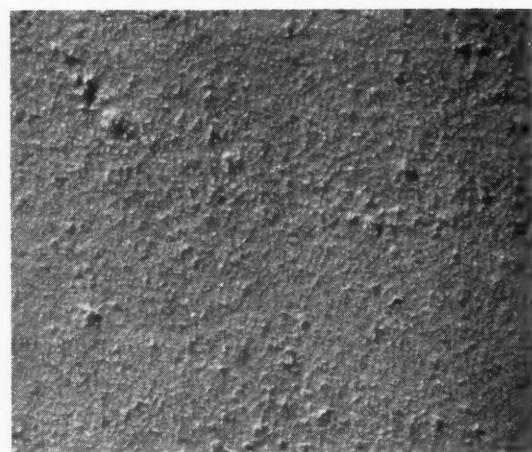
above 3000 F requires an extensive knowledge of the environment to which the material will be exposed, direct access to test facilities where the materials can be exposed to the environment, and immediate use of test results to modify materials-engineering programs while they are in formative stages. The development of a composite material will therefore require the same engineering approach in an aerospace system as do the other aspects of the system, such as aerodynamics, heat transfer, structure, controls, etc. What we have to say will illustrate, we hope, this concept of the user developing specialized material systems for aerospace utilization.

New Composite Systems

The type of metal-ceramic composite material that will be discussed is an extension of the concept developed for metal-fiber-reinforced ceramics, and the reinforcement principles apply for both types of materials. The principal difference between metal-fiber-reinforced ceramics and the sheet- or wire-reinforced ceramics discussed here are the dimensions and configurations of the reinforcement and the types of ceramic mixes that can be used. In felted-fiber-reinforced ceramics, the mean distance between adjacent fibers requires that the ceramic be impregnated by means of a liquid slurry. This type of impregnation requires a pressing and sintering operation to produce usable quality shapes. The use of metal-sheet or wire-reinforcement configurations opens up the spacing between adjacent reinforcement elements, thereby permitting a large variety of ceramic consistencies and application methods to be used.

The work performed by the authors in the field of

Texture of Ceramic Matrix

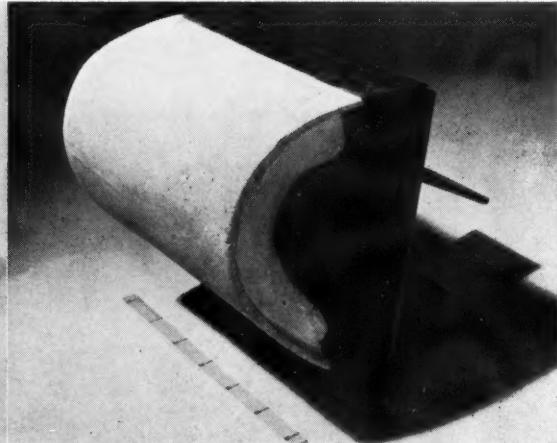
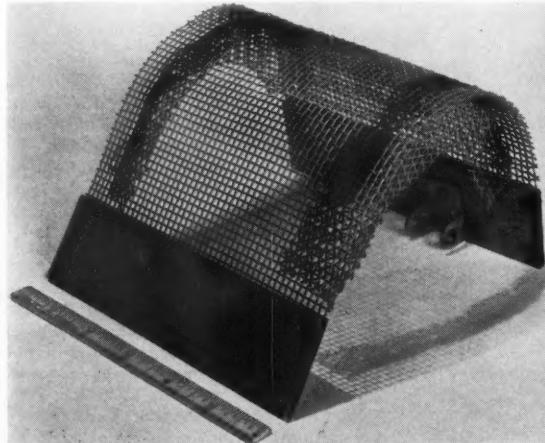


reinforced ceramics pioneered in the field of trowelled-on sheet- or wire-reinforced ceramics. The work to date has produced extremely promising composite systems for use as insulating coatings or structural elements in large sizes for cyclic service up to approximately 4500 F.

The reinforcement of ceramic bodies by additions of metal in sheet or wire form requires that certain factors be adhered to in order to prevent fracture of the ceramic due to metal inclusion planes of weakness. These can be summarized as follows:

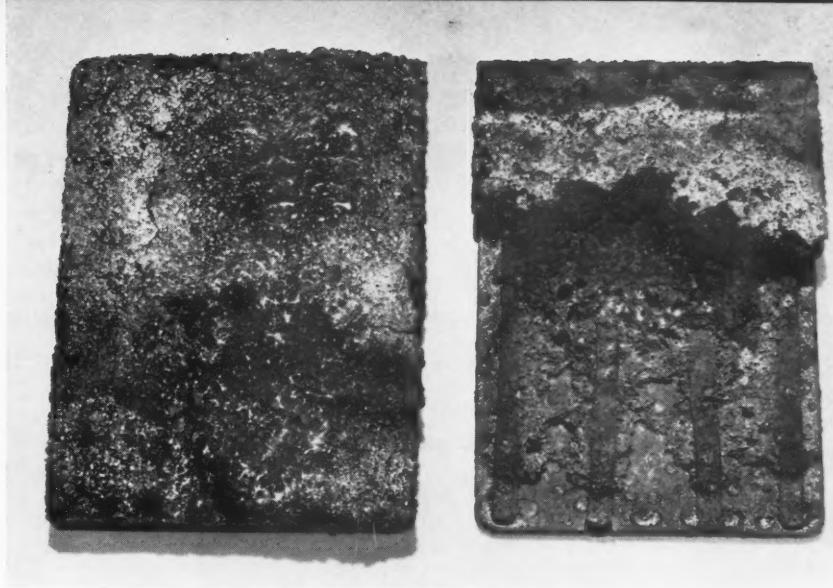
(a) The expansion coefficients of reinforcement and ceramic matrix must be compatible. They do not necessarily have to be the same level.

(b) The reinforcement metal spacing should be such that the void space will produce an unreinforced ceramic column of sufficient strength to with-



A striking example of the possible applications of metal-ceramic structures for spacecraft: An experimental wing leading edge for a hypersonic vehicle—left, molybdenum-mesh form with stiffeners and, right, composite structure with ceramic applied.

Ceramic on reinforcing base looks like this after seven cycles of being plasma-torch heated to 4200 F for $2\frac{1}{2}$ min, cooled with an air blast at a rate of 650 F per sec to 1000 F, and then cooled somewhat slower to room temperature. The stripped specimen at the right reveals that this treatment does not oxidize the reinforcement of the base.



stand thermal and mechanical loads and yet not large enough to build up a thermal gradient sufficient to produce fracture. Void spacings varying from $\frac{1}{8}$ to $\frac{1}{4}$ in. have proved to be satisfactory.

(c) The reinforcement metal configuration and location in the matrix should not produce in-line planes of weakness in the matrix along which cracks can propagate. The photo on page 27 shows some of the types of metal reinforcement that have been successfully used.

(d) The thickness of the metal reinforcement should be limited to that which will remain flexible with respect to the ceramic under applied thermal and mechanical loads. Thicknesses and widths ranging from 0.125-in.-wide by 0.010-in.-thick strip to 0.020-in.-diam wire-woven mesh represent the successful limits in reinforcements used to date.

(e) The ceramic should have a level of porosity that will enable it to act as a mosaic under thermally or mechanically induced deflections. Porosities ranging from 20 to 40% have proved successful. The photo on page 28 shows the type of ceramic structure used in the composites.

In addition to assuring that the metal reinforcement will not contribute to the uncontrolled fracture of the ceramic matrix, several other factors must be considered in developing a reinforced ceramic for a specific application.

For example, if it is desired to use the composite as an insulating coating for a metal-wall combustion chamber, a means of securing the reinforcement to the wall must be developed. The refractory metal selected for the reinforcement must be protected against internal oxidation if it is to use the component in an oxidizing atmosphere. The coating surface emissivity must be modified to serve best the particular application. Total normal emissivities varying from 0.2 to 0.85 can be developed in

alumina- and zirconia-based ceramics. If it is desired to apply the coating as thermal insulation on comparatively large bodies, a simple, economical method of application must be devised, and a composition must be selected that can be cured or set at relatively low temperatures. These and many other considerations are required before a composite design can be successfully developed into a usable material.

Metal Reinforcement Problems

The presence inside a ceramic matrix of relatively large masses of metal with physical properties that do not match those of the ceramic can cause reliability problems in severe thermal gradients or over long distances (several feet), unless a detailed distribution of heat throughout the system is known. A heat-transfer program can produce valuable information to guide the materials engineer in the selection of the reinforcement and ceramic-matrix materials, their thicknesses, the relative distribution of materials in the composite, and other factors in the over-all development of the system.

The concept of producing a reinforced-ceramic coating capable of insulating a combustion chamber by reducing its operation temperature by at least 500 F was achieved by the development of a stainless-steel corrugated-strip-reinforced aluminum-phosphate-bonded alumina. The composite material that resulted has been used successfully in ramjet combustion chambers up to several feet in diameter and 8 ft long. Its use has also been extended to structural applications such as the wing-leading-edge configuration, shown on page 28, by substituting molybdenum wire mesh precoated with a pack cementation coating (CONTINUED ON PAGE 58)

Expandable structures for space

Manned space stations, re-entry gliders, and such components as solar collectors acquire new design dimensions through an imaginative application of some new twists on old techniques

By J. T. Harris and F. J. Stimler

GOODYEAR AIRCRAFT CORP., AKRON, OHIO

EXPANDABLE structures are seriously contemplated for space vehicles. The term, "expandable structure," means a structure constructed of flexible materials which can be packaged into a small volume, and upon command, expanded into its useful shape by inflation.

The advantages of this structural concept exist in its unique capabilities for packaging, ease and reliability of deployment and erection, lightweight, and structural recovery after overload.

Goodyear Aircraft has developed this concept into a large number of structural applications including such flight articles as the nonrigid airship and the Goodyear Inflatoplane, as well as inflated radomes for large radar antennas.

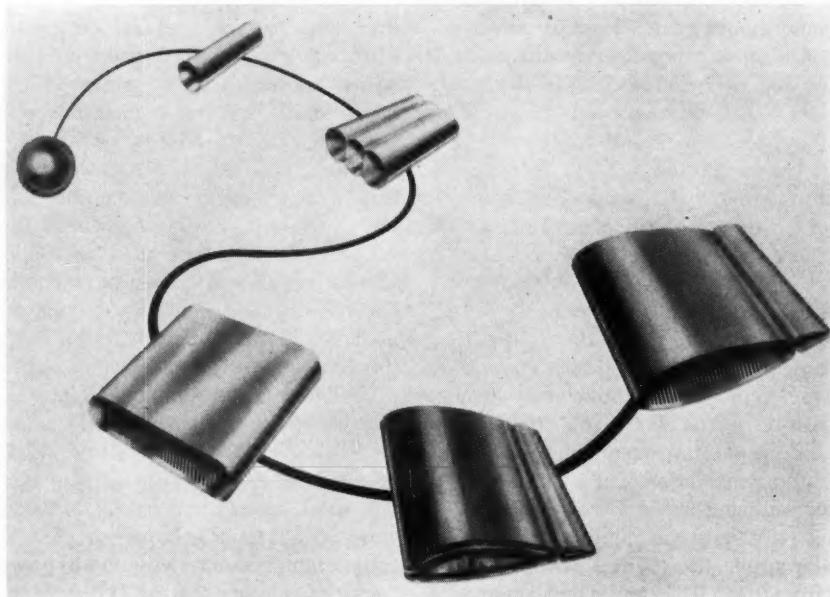
A more recent development has been the stabilization balloon for high-altitude and high-speed ap-

plication. This concept offers replacement of the parachute or other conventional drag bodies by providing positive and predictable characteristics in this regime of operation.

The outstanding advantages of this structural approach and the degree of success achieved in its application led naturally to its consideration for space application. When considered in the light of availability of payload and performance of present state-of-the-art boosters, the advantages of the packageability feature for minimum drag, and lightweight structural feature for maximum range, make this structural concept appear to have high potential for early success.

Expandable structures, fabricated from woven flexible materials can now be constructed in any shape desired. Ordinarily an inflated structure

Typical Shapes for Expandable Structures



takes the shape of a body of revolution. Modification of this shape was developed by introducing an internal member along the diameter of a cylinder and then by shortening this member, creating a two-lobed cylinder. When this is repeated in each of the lobes thus formed, the ultimate result is essentially two flat fabric surfaces connected by a series of vertical elements which can be pressurized to act as a structure. This construction is known as "Airmat" and can be woven as one integral piece of cloth. Various such structural shapes are shown in the illustration on the opposite page. The cross section of the Airmat can be varied by changing the gage blocks which regulate the depth of the Airmat on the loom. The original "Inflatoplane" wing was constructed of flat pieces of Airmat. However, a contoured NACA 0015 airfoil section is now maintained on the loom.

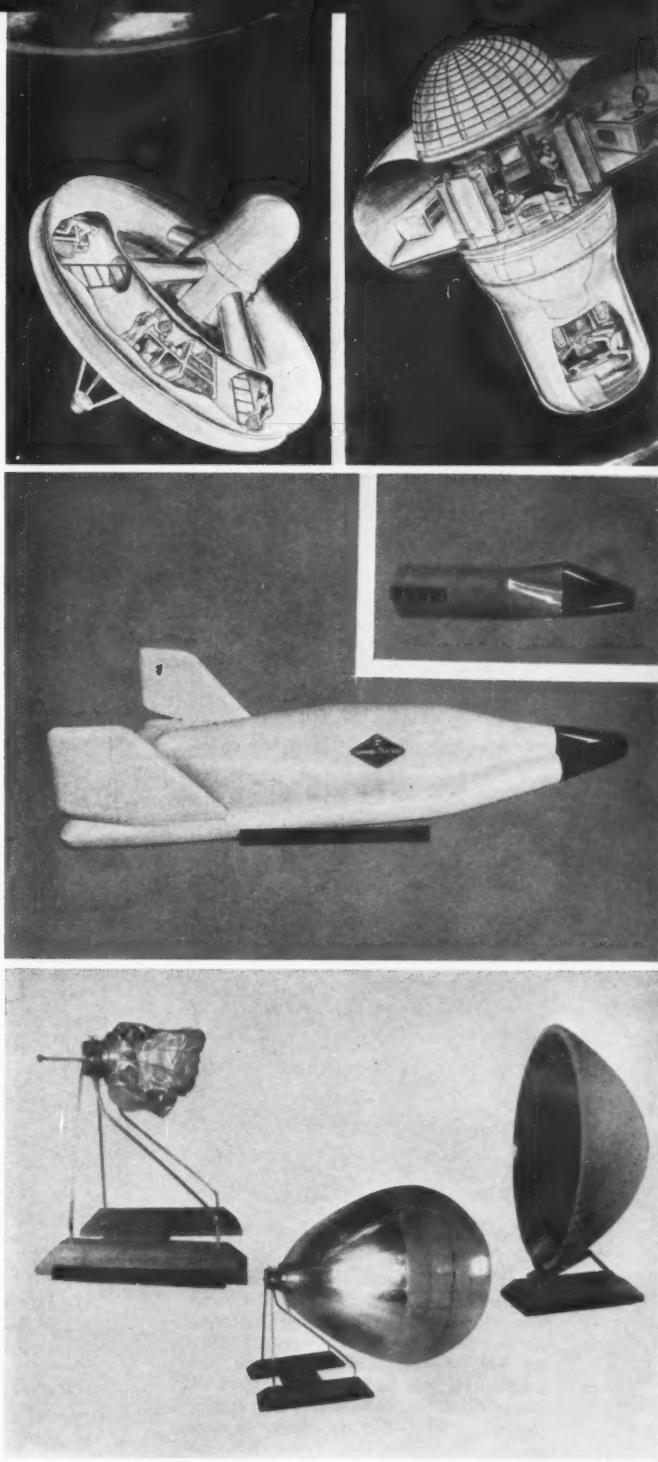
From a consideration of intended use and operating environment, the requirements of materials for space can be subdivided into three categories: (1) Manned orbital operation, (2) unmanned orbital operation, and (3) re-entry. Manned orbital flight in space stations requires high-strength materials because of the structural loads associated with a pressurized breathable atmosphere. Unmanned orbital operation requires lightweight, minimum-strength materials since the external applied loads will be small. Re-entry conditions dictate a material with the capability to resist the heat associated with this operation, while retaining sufficient strength for satisfactory functional performance.

In view of these general requirements, Goodyear conducted, under NASA contract, design and stress analyses and development tests on cord-type materials for an interrupted-torus space station concept. Methods of fabrication and packaging were studied to simplify design and minimize weight. Butyl and neoprene elastomers used with nylon are presently being considered as adequate materials based on high-vacuum and ultraviolet test data and fabrication requirements.

A three-ply, nylon-neoprene cord fabric of 0.79-lb/ft² weight possessed strength characteristics above 2000 lb/in. A cord-type fabric was designed to develop full-strength characteristics of the yarns in the meridional direction where maximum stress occurs. The bias plies were used to supply structural rigidity in addition to improved strength for the fabric. The illustration at the top here shows two representative GAC concepts based on the latest design information.

Continuous torus and C-annular torus configurations were generally 20 to 40 ft in diam with about a 7- to 10-ft cross-section diameter. Working pressures of 7 to 10 psi were considered adequate. High-altitude balloon tests have been considered for the C-annular con-

(CONTINUED ON PAGE 92)



Illustrations and models depict important areas of current study with expandable structures: Top, manned space stations, annular and C-annular designs; middle, the reentry glider (shown packaged in the inset); and bottom, solar concentrators, here represented by a sequence showing expansion.

Reinforced carbonaceous materials

They offer one means of extending the performance of state-of-the-art reinforced plastics above the 1000-F level—perhaps to 5000 F—into the useful range for glide re-entry vehicles

By Brennan A. Forcht and Milton J. Rudick

CHANCE VOUGHT CORP., ASTRONAUTICS DIV., DALLAS, TEX.

THE aerospace-vehicle designer is searching for efficient, reliable heat-resistant materials to solve an array of thermal problems with rocket nozzles, nose cones, leading edges, structural panels, and nuclear-engine components. Possible solutions have involved materials ranging from low-temperature-resistant thermoplastics to the refractory metal alloys, graphite, ceramics, and cermets. Various systems have been devised to avoid high-temperature design problems by literally carrying the heat away as rapidly as it enters the structure.

For the special case of glide re-entry vehicles, which are exposed for a relatively long time to a high-temperature environment, requirements for a lightweight, thin-gauge outer heat shield are now being met by refractory metals. These are heavy, costly, relatively difficult to fabricate, and, at present, not readily available in desired gauges and sheet sizes.

One approach to an effective thermal barrier for re-entry vehicles is through organic plastics. These materials, backed by a long history of airframe design and field experience, in contrast to their refractory relatives, lend themselves readily to complex component fabrication. Organic plastics at the present state of development have usable strengths up to about 700 F, with some extension to 1000 F when exposure times of 1 to 2 min exist. By ablating, these materials can cope with the high surface temperatures generated during re-entry.

It has been observed that organic plastics, such as the phenolics, which tend to char at the ablating surface, perform significantly better when exposed to extreme heat sources than those such as Teflon which act as pure sublimators. A logical explanation for this superiority lies in the fact that the char-forming plastics not only incorporate the principles of cooling by ablation but also back-radiation. In addition, the char layer serves further as a fractionator of the distillate products of the subsurface virgin-plastic material. This latter capability permits a large volume of low-molecular-weight gases to be made available at the surface for blocking convective heat transfer.

The effectiveness of the char in providing these desirable features depends on its structure and also on the length of time that it is structurally attached to the base plastic system during the ablating process. As known today, char-forming organic-plastic-based material systems are seriously deficient with respect to both



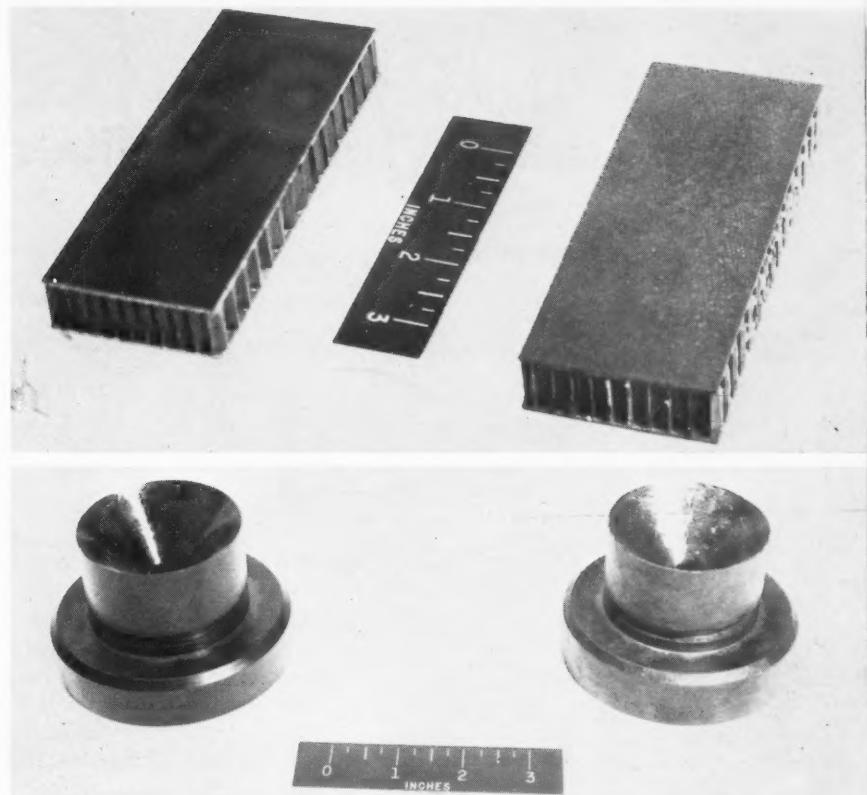
Forcht

Rudick

Brennan A. Forcht has since 1951 worked on structural materials at Chance Vought. Now supervisor of its materials development group, he has responsibility for Vought Astronautics materials programs. He has an M.S. in chemical engineering from Rensselaer Polytechnic Institute and a B.S. in chemical engineering from Brooklyn Polytechnic Institute.

Milton J. Rudick joined Chance Vought in 1944, and served as supervisor of its structures materials group and chief of its structures test laboratory before his present assignment as chief of the Space Technology Section of its Astronautics Div. He was a member of the NACA subcommittee on materials, is now a member of the AIA aircraft research and testing committee and a member of the NAS Materials Advisory Board.

These photos of a fiberglas honeycomb structure and a nozzle insert before and after thermal conversion ("before's" at left) illustrate findings that, under controlled conditions, the resin component of a laminated solid can be carbonized yet the resulting body retain its original volume and shape and much of its original mechanical strength.



of these areas. Initially, with present systems, the char formed is uniform and continuous in nature. However, with increasing exposure time the char layer thickens, becoming dense on the outer surface and becoming highly porous in the region adjacent to the virgin-plastic layer.

Eventually the outer layer is not sufficiently permeable to permit transmission of the gases produced, and a separation occurs in the structurally weak porous strata of the char layer. The resultant change in aerodynamic configuration continues until either the mission is accomplished or the material has completely disintegrated. Thus it is evident that in order to provide a highly effective thermal shield of constant aerodynamic configuration, a structural char of uniform porosity is desired.

Reinforced carbonaceous material systems present an approach for developing the desirable structural char layer of uniform porosity as well as a lightweight, thin-gauge heat-resistant sheet.

I. E. Harder and J. D. Culp of Chance Vought prepared reinforced carbonaceous materials by reduction of the organic portion of a fiberglas-resin laminate. The resin was thermally decomposed, leaving a carbon residue which held the fiberglas laminate in its original shape. Additional studies,

which will be described shortly here, have revealed that under controlled conditions the resin component of a laminated solid can be carbonized and still retain its binder function. The resultant reinforced carbon bodies have essentially the same volume and configuration of the original unreduced body, as indicated in the photos shown above, and a substantial part of its original mechanical strength.

Two primary components of reinforced carbonaceous materials influence the properties of the basic product: The resin binder, and the complementary reinforcement agent utilized.

In an early Chance Vought study it was pointed out that the resin, after transformation, should provide, among others, the following desirable features:

High carbon residue for structural binding.

High strength for load transmission.

High available porosity for subsequent processing, gas-producing impregnants, and oxidation protection.

Volume stability for compatibility with reinforcement and over-all dimensional control.

It can be seen, then, that in selecting resins suitable for thermal decomposition careful consideration must be given to fac- (CONTINUED ON PAGE 88)

New shapes for glass fibers

Low density without loss in strength, with more versatile form—the hollow glass fiber in reinforced-plastic composites shows promise of meeting these new goals for space-vehicle structures

By Irving J. Gruntfest and Norris F. Dow

GE MISSILE AND SPACE VEHICLE DEPT., PHILADELPHIA, PA.



Gruntfest

Dow

I. J. Gruntfest is a consulting chemist to GE's Missile and Space Vehicle Dept., specializing in the application of modern physical chemistry to the solution of problems in plastics technology. Between 1941, when he received a Ph.D. in physical chemistry at Cornell Univ., and 1956, Dr. Gruntfest held research positions with Bell Labs and Rohm and Haas and worked on polymers, resins, and plastics. He is currently the chairman of the NAS Materials Advisory Board's research and testing panel on plasma phenomena.

Norris F. Dow is an engineering consultant to GE's Missile and Space Vehicle Dept. on heat-protection systems, materials, and structures for advanced design of re-entry and space vehicles. Upon receiving a degree from Brown Univ. in aeronautical engineering in 1939, he joined the Langley Structures Research Div., where as head of the Airframe Components Branch he was responsible for the preliminary feasibility study and design of the structure for the X-15, as well as conducting a variety of research on materials and structures. Recently he has been a member of the NAS and NASA research advisory committees on missile and space-vehicle structures.

WHEN only a few elaborately engineered items are to be manufactured, as is often the case with missiles and space vehicles, high material costs may be easily lost in the design cost. Furthermore, even if large numbers of items are planned, the cost of accelerating these to high velocities allows the use of expensive materials if weight can be saved. Particularly, since cost has had a profound influence on the development of plastics, is it appropriate to reconsider the state of the art of structural plastics for flight applications, to determine whether further progress will be rapid and fruitful, and whether there are some new directions for possible improvements.

Many types of flight structures have already capitalized on the characteristics of plastics. It may be recalled that the first important structural products made from glass-reinforced plastics were radomes during World War II. The selection of the material in this case was dictated not by its mechanical, but by its electrical properties. In a similar negative fashion, from the point of view of utilizing favorable structural strengths, the fabrication of a reinforced-plastic wing for an airplane was undertaken

Measured Tensile Strengths of High-Performance Structural Materials

Material	Density (lb/cu in.)	Strength (psi)	S/D Ratio (in. x 10 ⁻⁶)
Glass-reinforced Plastic			
Type 1 ^a	0.065	250,000	3.85
Type 2 ^b	—	230,000	3.54
Type 3 ^c	—	135,000	2.08
Steel ^d	0.282	300,000	1.06
Titanium Alloy B-120 VCA ^e	0.175	257,000	1.47
Aluminum Alloy 7075-T6 ^f	0.101	83,000	0.82

(a) Unidirectional web impregnated at spin bushing (Materials and Processes Inc.).

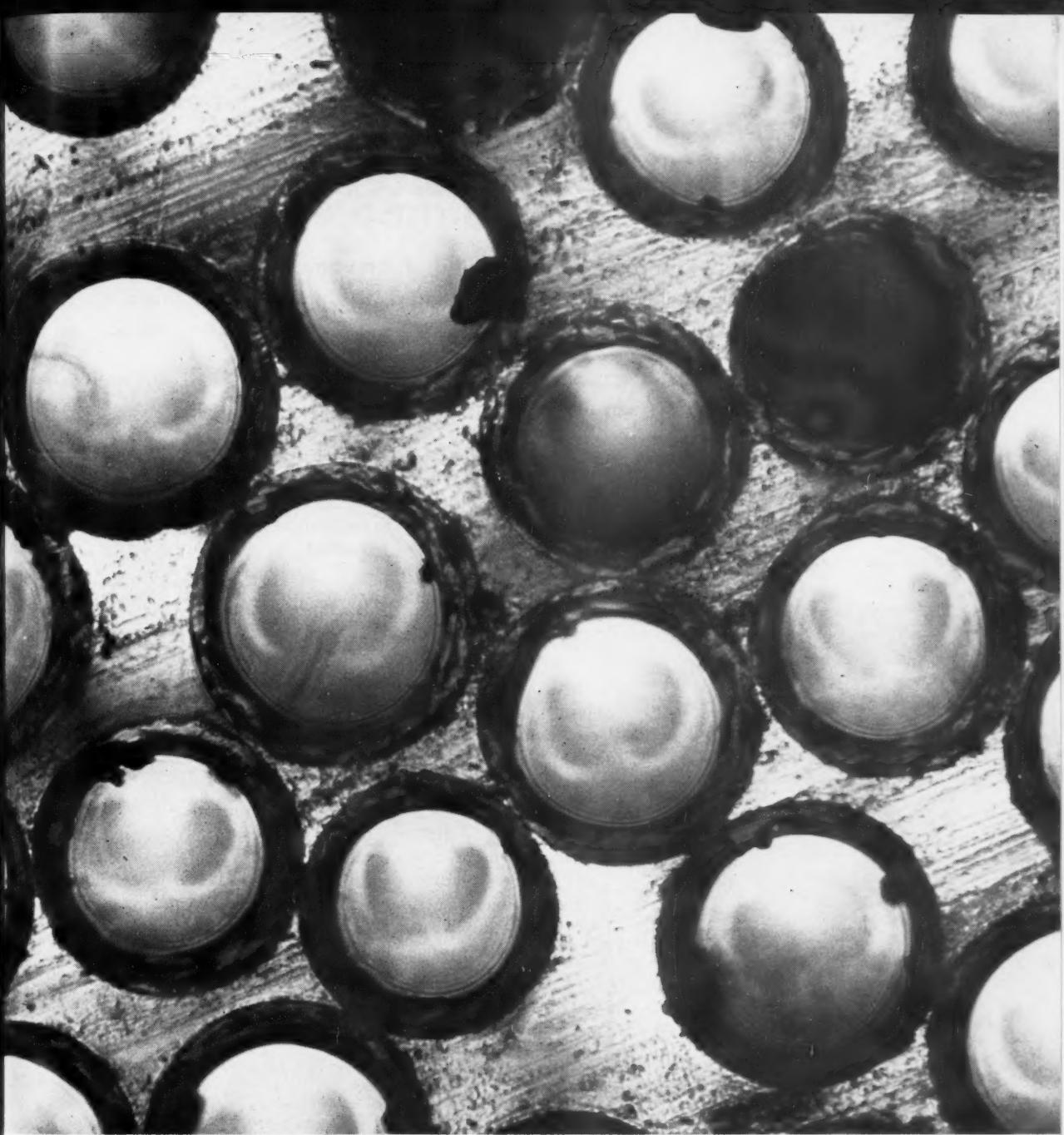
(b) Unidirectional filament wound (Owens-Corning Fiberglas Corp.).

(c) Bidirectional filament wound (Owens-Corning Fiberglas Corp.).

(d) Highest values in 1959-60.

(e) Highest value in Crucible Steel circular.

(f) Highest value in Alcoa aluminum handbook.



Hollow-fiber reinforced plastic, shown in cross section, magnified about 800 times, advances toward new goals of low density, high compressive strength, and versatile form for composites, which are already prominent in space-vehicle construction.

in 1952 to avoid the use of strategic material. (The plastic wing was reported to be lighter and *no more costly* than the metal structure it replaced.) Missile and space-vehicle structures designed for tensile loadings, on the other hand, have used plastics just because of the weight advantage associated with the high specific strengths. Good examples of these structures are the filament-wound rocket-motor cases for the Minuteman missile's third and fourth stages.

Weight for weight, reinforced plastics are now recognized as stronger than any other structural material for many applications. The basis for this can be seen in part from the table on the opposite page which summarizes currently available tensile strengths of plastics as compared with metals. Not only is the strength-to-weight ratio of the plastic highest, but even more significantly the density is the lowest.

(CONTINUED ON PAGE 80)

Tungsten-base composites

Now tested in both the laboratory and the field, these composites show promise as a high-performance nozzle material

By Samuel R. Maloof

AVCO RESEARCH AND ADVANCED DEVELOPMENT DIV., WILMINGTON, MASS.

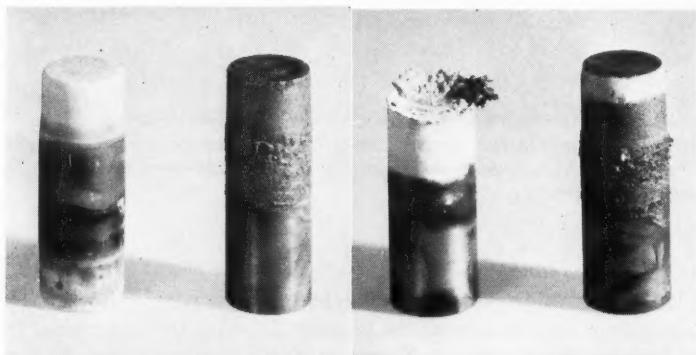


Samuel R. Maloof, a principal scientist in Avco RAD's Materials Dept., is now on leave at MIT, where he is conducting research with E. Orowan on brittle-fracture phenomena in tungsten. With Avco since 1958, his background includes a Ph.D. in metallurgy from Pennsylvania State Univ. in 1949, supervision of groups doing research on materials for nuclear and thermionic applications at Raytheon and Nuclear Metals Inc., and direction of the Avco RAD's metal-processing group, where he was responsible for the development and fabrication of refractory metal-base composites for high-temperature applications. Dr. Maloof has authored several papers on the use of X-ray diffraction and electron microscopy in metallurgical research and has done work on the deformation and fracture of beryllium and tungsten.

THE TREND has been toward higher and higher combustion temperatures in rocket motors. Keeping rocket-nozzle technology up with this trend has become an important challenge to the materials and structures engineer.

Consider, for example, pure tungsten, one of the most reliable high-performance nozzle materials evaluated to date. The pure metal has a melting point (6170 F) lower than that of some of the more refractory carbides and pure graphite. It is limited to applications where exhaust gases in contact with it do not exceed about 5600 F in temperature.

We will need materials with properties better than this admirable metal has to offer in the future. For some time now Avco has recognized this and has had in development tungsten-base composites capable of operating under gas temperatures above the melting point of pure tungsten. These composites are already being marketed under the trademark "Avcomet" (patent applied for). The proprietary nature of this brand of composites prevents us from discussing microstructural detail, composition, and methods of fabrication. But we can look at the performance of Avcomet as indicative of approaches being taken to nozzle technology and of the state of the art in an important area of (CONTINUED ON PAGE 56)



Photos show results of subjecting pure tungsten and Avcomet-1 specimens to a nitrogen-stabilized 500-kw arc. Tungsten is at the left in both photos. Left photo shows specimens after a 60-sec run with gas enthalpy (H/RT_0) of 100 and heat flux of 750-Btu/ ft^2/sec ; right photo, tungsten after 30 sec and Avcomet-1 after 60 sec in arc with enthalpy of 200 and flux of 1280 Btu/ ft^2/sec .

Part 1—Feasibility

Deep-space communications

On the point of burgeoning, U.S. missions into deep space will pay off in direct proportion to skill in communications engineering . . . Studies have made feasible approaches clear

By Eberhardt Rechtin

NASA JET PROPULSION LABORATORY, PASADENA, CALIF.



Eberhardt Rechtin is director of the NASA Deep Space Instrumentation Facility, with headquarters at the Jet Propulsion Laboratory of CalTech, and in recent years he has headed the JPL Communications Div. and Guidance Div. Since his association with JPL began more than a decade ago, when he received a Ph.D. in electrical engineering from CalTech, Dr. Rechtin has made important contributions in the fields of radio-propagation, noise and filter theory, missile guidance, secure-communication systems, and countermeasures. He has been responsible for directing much of the JPL effort in space communications and tracking, including the design and development of the Microlock system for Explorer satellites and the Trace system for Pioneer IV. A senior member of many societies including ARS, Dr. Rechtin received the Westinghouse Science Talent Award in 1943, was a Cole Fellow in 1947, and a National Science Fellow in 1948.

HIGH-quality communications between earth stations and probes exploring the moon, the nearby planets, and interplanetary space is quite practical and, although it will require engineering of high order, it does not require breakthroughs or the discovery of new principles. As a matter of fact, usable communications to the edge of the solar system is essentially within the state of the art. Communications to probes well outside the solar system is presently impractical. On the other hand, much the same statements can be made about the practicality of such far-ranging probes themselves.

Space communications almost always involves line-of-sight transmission—transmission in which the transmitter and receiver have a clear view of each other. It is certainly possible to envision situations in which this is not the case, but most such situations can be solved using a radio-relay spacecraft which is simultaneously in line of sight to the earth and to the obscured probe. Alternatively, data can be stored during obscured periods for later transmission in the clear. To prevent the rotation of the earth from interrupting communications, a network has been established of three stations located about 120 deg apart in longitude—in California, Australia, and South Africa. These three comprise the basic elements of the NASA Deep Space Instrumentation Facility.

The essence of quality deep-space communications is reliability and efficiency. Reliability is particularly difficult to achieve in deep-space missions because of the very long flight times of the probes in a largely unknown environment. Efficiency can be achieved in the probe by the use of efficient transmitters and receivers, of course, but far more by the use of directional antennas. Directional spacecraft antennas require attitude-stabilized spacecraft—which certainly does not simplify the reliability problem. Such stabilization is also needed for a host of other functions, including guidance, surveillance, and maneuvers.

The attitude-stabilized spacecraft, shortly to appear on the scene in the NASA Ranger series, unquestionably spells the difference between obtaining quantities of interesting information about the planets and obtaining so little data that the desirability of even attempting planetary exploration might be questioned.

Efficiency of reception at the earth stations will give a direct payoff. It really pays to use fine antennas, very sensitive receivers, and other ground equipment of high quality (CONTINUED ON PAGE 42)

Lithium and sodium for underwater propulsion

The necessary high performance for certain underwater vehicles
can come from these powerful water-reactive metals used as fuel

By W. D. White

U.S. NAVAL ORDNANCE TEST STATION (NOTS), PASADENA, CALIF.

TRADITIONALLY, the designers of powerplants for underwater propulsion have considered the sea as an alien environment. An essentially impervious shell surrounds the various components of these powerplants, and everything needed for their operation is installed before these small preserves of atmospheric conditions are sealed up and sent on their way. There are many similarities between this concept and the rocket-propelled vehicles which are designed for operation in the alien environment of extremely high altitudes or interplanetary space. However, we all know that rockets are not the most efficient way of propelling a vehicle through the atmosphere, since a great deal of space and weight can be saved by inducting the surrounding air to react with a relatively small amount of fuel carried in the vehicle.

The use of water-reactive fuels for underwater propulsion alters the design concept; from an alien environment which must be sealed out, the sea turns into a co-propellant which is taken in and utilized in much the same manner as the atmosphere is used by an air-breathing engine. This concept is not entirely new, because as early as 1865, Jules Verne, in his famous novel "20,000 Leagues Under the Sea," referred rather nebulously to the use of sodium as the fuel which powered his fictional submarine Nautilus.

A more up-to-date program on water-reactive fuels, however, has been conducted at the Pasadena Annex of the U.S. Naval Ordnance Test Station by members of its Propulsion Div. under the direction of R. C. Brunfield. This work, summarized here, was aimed at developing ways and means of handling and reacting molten sodium and lithium with sea water to produce a working fluid of high temperature and pressure which could drive a gas turbine for underwater propulsion.

The program began with certain theoretical considerations. Sodium metal melts at 98°C and reacts violently with water even at room temperature. Lithium metal melts at 186°C and reacts quietly with water at room temperature. Although molten lithium reacts rapidly with water, it is much less reactive than molten sodium under the same conditions.

Thermodynamic calculations were made by J. M. Carter, L. R. Rapp, and myself on the reactions of these metals with water and the effect of the excess water added to lower the flame temperature and increase the gas content of the working fluid, using the following



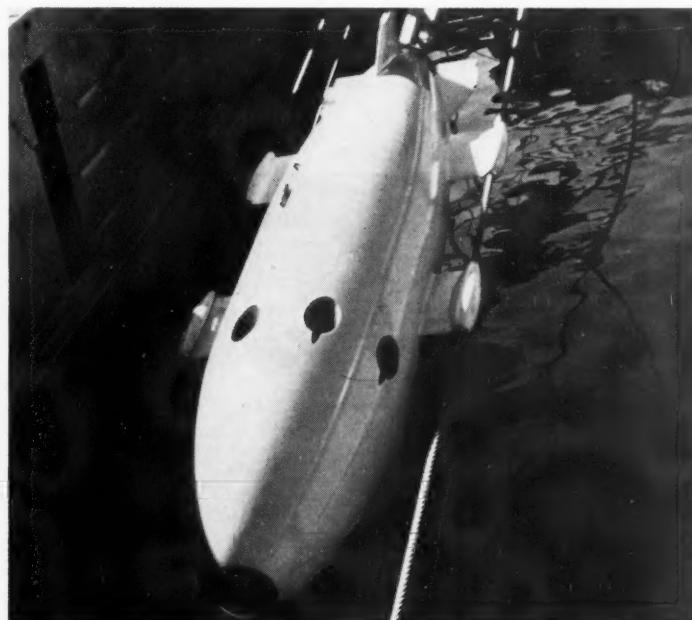
W. D. White is head of the Thermodynamics Branch in the Propulsion Div. of the Underwater Ordnance Dept. at the Pasadena Annex of the U.S. Naval Ordnance Test Station. Coming to NOTS in 1948, upon graduating from Ohio Univ. with a B.S. in chemistry, he has since been engaged in research on water-reactive and other high-energy propellants and on the design and development of combustion systems for advanced underwater propulsion.

general equations:

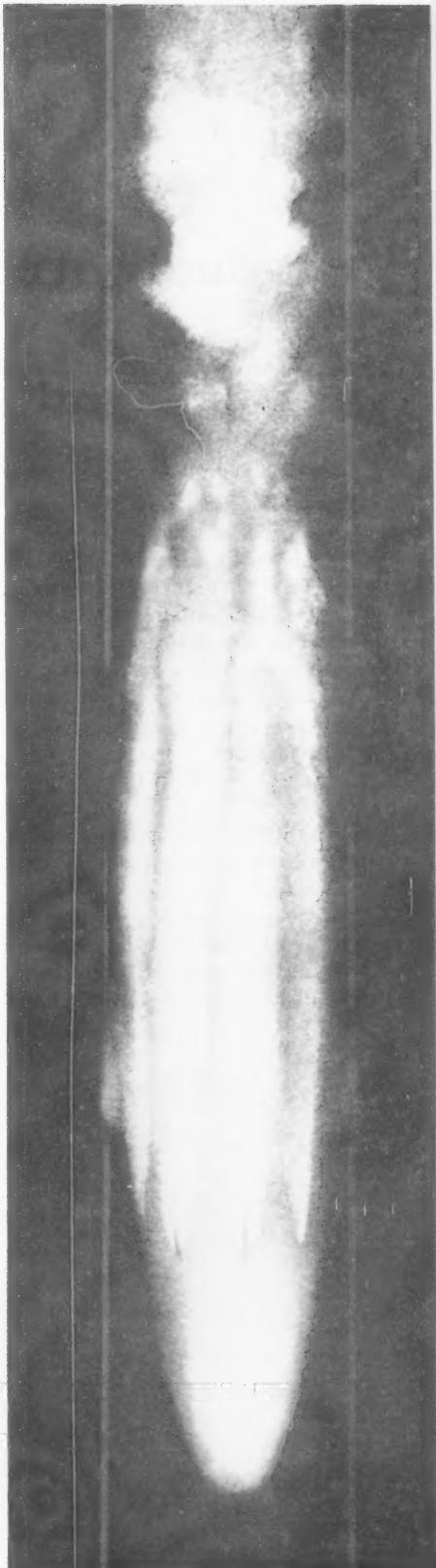


The first graph on page 78 illustrates the combustion temperature (T_c) calculated for various weight ratios of water to lithium, and the temperature after expanding the reaction products from 300 psia to atmospheric pressure (T_E). The horizontal portions of the curves indicate the regions where an equilibrium exists between two different forms of the reaction products. For instance, the plateau in each curve near a mixture ratio of 4 to 5 indicates the equilibrium between lithium oxide and lithium hydroxide. The small flats at mixture of 8 and 10 reflect the melting point of lithium hydroxide (735 K). At mixture ratios higher than 12 or 13 the generated heat is insufficient to vaporize all the excess water, and an equilibrium exists between steam and liquid water in the reaction products.

The next graph, at right of the first, gives the performance parameters calculated from the enthalpy drop between the temperature shown in the first graph. It is interesting to note that the maximum specific energy (E_{sp}) is obtained at a fairly high mixture ratio of about 9 lb of water per pound of lithium, corresponding to a combustion temperature of about 850 K (1070 F). (Specific energy is a very convenient parameter derived early in this program. It represents the kinetic energy available in a jet, expressed as horsepower-seconds per pound of water-reactive fuel, and also gives directly the horsepower which would theoretically be produced by a one-pound-per-second flow rate of fuel.) The reason for this is, of course, that only the weight of lithium is taken into account, plus the fact that the amount of gas produced per (CONTINUED ON PAGE 78)



An NOTS underwater test vehicle for evaluating propulsion systems such as the one discussed here. Right, the vehicle in action.



Space Flight Report to the Nation Interim Report

Industry response builds SFRN

Already exhibitor response assures that the SFRN will double, and perhaps quadruple, the scope of any ARS meeting yet held

RESERVATIONS have now been made for more than half of the exhibit space at the AMERICAN ROCKET SOCIETY'S SPACE FLIGHT REPORT TO THE NATION, to be held in the N.Y. Coliseum, October 9-15, this year.

Initial exhibitor response guarantees that the meeting will be twice the size of the biggest previous annual meeting—the one in Washington, D.C., last year—and if all the exhibit space is taken, it will be four times as large as any previous meeting.

At present 104 exhibitors have made commitments, taking 57% of the available exhibit space. Of these exhibitors there will be 25 who have never before participated in an ARS exhibit. Last year's annual meeting in Washington had the largest previous number of exhibitors—63 in all.

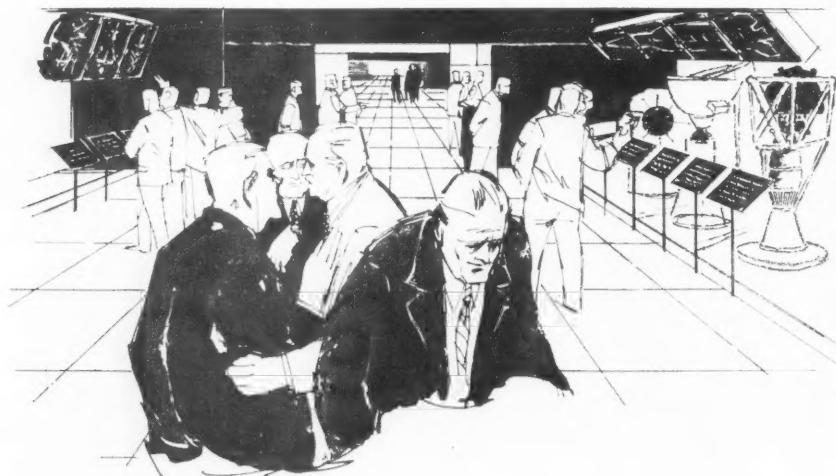
A big factor in the popularity of this year's meeting has been the innovation called "exhibiting in depth." This type of exhibiting provides space on

both sides of an aisle, allowing spectators to walk through an exhibit rather than just pass by it. Over 60% of these booths have already been reserved by a total of 32 companies.

Three floors of the Coliseum will be utilized for exhibit space. The entire second floor of the Coliseum has already been reserved. This floor, with the exception of the perimeter booths, will be comprised entirely of island booths. Island display limits the total number of booths on the floor to 33, but allows the exhibitors to add depth and drama to displays.

The three largest displays on the second floor will be a NASA-DOD exhibit, an ARS exhibit designed by Raymond Loewy, and a General Motors display. General Motors will occupy two of the islands and two of the perimeter booths, amounting to 264 running feet and an area of 4000 net square feet.

♦♦



ARS Space Flight Report to the Nation

OCTOBER 9-15, 1961

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Miss Sylvia Peltonen, Secretary
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NOTE: There will be an interval of several weeks before you can expect to receive a direct confirmation from the hotel accepting your reservation. Room numbers cannot be assigned by hotels until guests register on arrival.

MAKE YOUR RESERVATION NOW

Deep-Space Communications

(CONTINUED FROM PAGE 37)

so that design margins can be kept low. And stations are intentionally located in remote regions free from as much man-made interference as possible.

Assuming that the appropriate engineering is accomplished, we will obtain TV from the moon, high-speed facsimile (slow TV) from the nearby planets throughout their trips around the sun, and cosmic-ray counts from the edge of the solar system.

In addition to the undeniable advantage of line-of-sight transmission—an advantage which is denied most earth communications—the deep-space instrumentation specialist enjoys the advantage that his vehicles are almost always on undisturbed, Keplerian trajectories. This fact means that deep-space tracking can be accomplished with great resultant accuracy without requiring ultrarefined techniques. Instead, using long integration times, general-purpose computers, sets of comparatively simple Doppler and range measurements taken at selected times, and readily available antennas, the designer can provide more than sufficient tracking. It is important that, in the list of techniques the tracking designer exploits, precision angle tracking—that most difficult of techniques—is *not* necessary. Sufficient tracking accuracies for all intended space missions can be obtained with angular accuracies no better than a few hundredths to tenths of a degree.

This discussion and one on design considerations to be presented in a following issue add substance to these admittedly qualitative statements.

Antenna Considerations

The ratio of received signal power, P_r , to transmitted power, P_t , is given by the following expression:

$$P_r/P_t = A_t A_r / (\lambda d)^2 = G_t G_r \lambda^2 / (4\pi d^2) = G_t A_r / 4\pi d^2 = G_r A_t / 4\pi d^2 \quad (1)$$

where A is the area of the appropriate antenna, G is the antenna gain, and d is the distance between transmitter and receiver. The question of which form of Equation (1) should be used

depends on whether gain or area is the more significant parameter in a particular application. For example, an isotropic antenna is defined as having unity gain, which makes its effective area a function of frequency. A parabola is better characterized by its effective area, which approximates its physical area; the gain of a parabola is therefore a function of frequency. Some of the appropriate relationships between effective gain and effective area are given in the table below.

This table refers to antennas in normal usage. If the various antennas are scaled appreciably larger or smaller than normal, these relationships no longer hold. If the area of a parabola is increased beyond normal size, transmission frequency remaining constant, a point will finally be realized where construction inaccuracies will make it impossible to use the complete physical area efficiently. Stated in different terms, if we attempt to make an antenna larger and larger, a point will be reached where it is no longer possible to make the gain of the antenna any greater without enormously refining the construction tolerances of the antenna. It can be shown that the degradation in effective gain (or area) due to surface irregularities, σ , is given by

$$A_{eff}/A_{\sigma=0} = G_{eff}/G_{\sigma=0} = e^{-16\pi^2\sigma^2/\lambda^2} \quad (2)$$

The effect of such degradations is shown in the graph on page 44. Antennas operated at or beyond the maximum gain point are said to be gain-limited. We might expect ground antennas, particularly, to be limited by this effect.

If the space vehicle's attitude cannot be controlled or if the vehicle's antenna cannot be pointed accurately enough, the amount of possible vehicle antenna beaming is also limited. For example, if the vehicle tumbles and rolls violently, the antenna must radiate uniformly into space and hence G is close to unity. The early satellites were close to this category; that is, the vehicle antennas were gain-limited. Within a very short time, however, space vehicles will be considerably different. Stabilization accurate to a few degrees will be achieved, making the use of antenna

beamwidths of a few degrees possible. Such narrow beamwidths are produced only by using significant antenna area. However, it is difficult to assemble large, accurate antennas, even in outer space.

For some years to come it will not be possible to make space-vehicle antennas as large, as accurate, and as controllable as earthbound antennas. As a consequence, the vehicle antennas will be limited by sheer size—in other words, area-limited. In the early stages of space exploration, areas of tens of square meters may be achievable. In the more distant future, areas of several thousand square meters may be possible. Even such areas, however, are small compared with those of earthbound antennas.

The appropriate forms for Equation (1) can therefore be written:

Application	Appropriate Form
Space-to-earth	$G_t A_r / 4\pi d^2$
Space-to-earth	$G_r A_t / 4\pi d^2$
Space-to-space	$A_t A_r / (\lambda d)^2$

The Interference Problem

If there were no interference of any kind, it would be possible to hear any transmitter at any distance by incorporating sufficient amplification in the receiver. Unfortunately, interference is always present and strongly limits the usable range of communications. Interference enters the communications system in several places: (1) In the transmitter, where it affects the stability and clarity of the signal in a spurious way; (2) in the transmitter-receiver space link, where its effectiveness depends on its intensity, direction of arrival, and spectral (frequency) characteristics; (3) in the input circuitry of the receiver, where random motion of electrons produces noise dependent on the temperature of the circuitry and the amplifier bandwidth; and (4) signal-generating circuitry in the receiver, where its effects are similar to transmitter perturbations. Interference entering on the link and interference generated in the receiver input circuitry are the most important of these possible sources.

Every effort is made to avoid external interference sources by locating the sensitive space-communications receivers as far as possible from civilization. As for the few interfering signals that might still be present, either the receiver must be designed to handle them individually or the experimenter must be prepared to read through such interference in the process of data reduction.

External interference may be minimized by careful design of antennas (including antennas that can almost cancel point-source interference by

Power Gain and Effective Area of Several Antennas

Antenna	Gain	Effective Area
Isotropic	1	$\lambda^2/4\pi$
Infinitesimal dipole	1.5	$1.5\lambda^2/4\pi$
Half-wave dipole	1.64	$1.65\lambda^2/4\pi$
Optimum horn	$10.0A/\lambda^2$	0.81A
Parabola or lens	$(6.3 \text{ to } 7.5)A/\lambda^2$	$(0.5 \text{ to } 0.6)A$
Broadside array	$4\pi A/\lambda^2$ (maximum)	A (maximum)

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pointing an antenna pattern null in the appropriate direction), by choice of frequency, and by appropriate coding of the transmission to make the signal distinctive.

Internal interference is one of the fundamental limitations in any measurement system. It is true throughout the realm of physics that the final sensitivity of instruments is limited by random internal activity. This limitation can be illustrated by the human senses. Even for people with perfect hearing, the smallest sound that can be heard is limited by the sounds of blood coursing through the arteries in the head. The faintest light that can be seen is limited by the faint spots produced by the moving fluids of the eye. Both the ear and the eye are capable of great amplification of very weak signals; yet infinitesimal signals can be neither heard nor seen because of the limitations of internal interference.

Exactly the same phenomenon occurs in radio receivers. In a conventional receiver, the principal source of internal interference is noise produced by the random motion of electrons in the input circuitry. Because conventional amplification at radio frequencies is achieved using vacuum tubes, whose basic principle is the violent excitation of electrons, the amount of noise activity at the receiver inputs may be 20 times as great as might be expected from the motion of electrons at ambient temperature.

It can be shown that the noise power produced in a bandwidth Δf is proportional to the temperature of the circuitry. In equation form,

$$P_n = kT\Delta f \text{ watts} \quad (3)$$

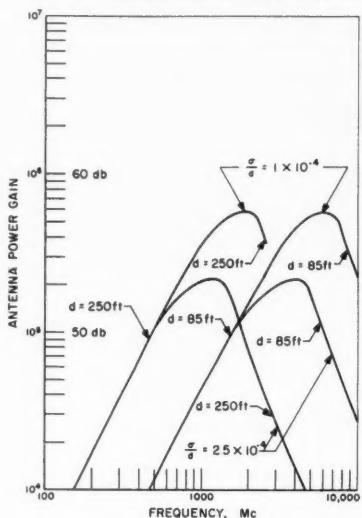
where P_n = noise power, watts; k = Boltzmann's constant $= 1.38 \times 10^{-23}$ w-sec/K; T = absolute temperature, K; and Δf = bandwidth, cps. Two ways of minimizing this source of interference are evident: Reducing T and reducing Δf .

Reduction of P_n by reducing Δf is limited by the desired rate of information flow. If the bandwidth is extremely small, information rate is very low. In normal, real-time usage, teletype requires approximately 100 cps, voice requires about 3000 cps, and television requires about 3×10^6 cps. It is therefore difficult to reduce Δf without reducing the usefulness of the radio link itself.

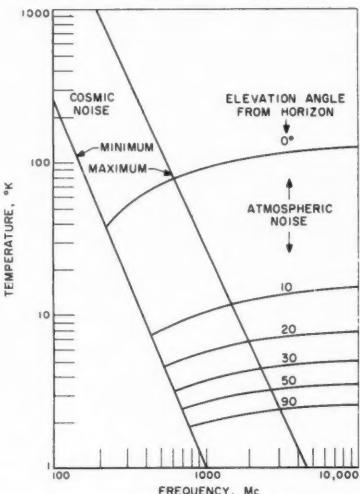
The temperature T is thus a critical factor in determining the feasibility of space communications. It has also a most significant relationship to the equivalent temperature of receivers, of the earth in the vicinity of the ground receiving antenna, of the atmosphere through which the radiation passes, and of the galaxy. The temperature T

to be used in Equation (3) is the weighted sum of all the different source temperatures, where the weighting factors depend upon how the source is "seen" by the receiving antenna. If the source is internal to the receiver or uniformly surrounds the receiving antennas, the weighting factor is unity. If the source occupies only a fraction of the surroundings, its weighting factor depends upon its size

Antenna Gain vs. Frequency



External Noise vs. Frequency



and upon its location in the antenna pattern. By definition, the maximum weighting factor for any source is unity. The weighted temperature ΔT (the change in T produced by an external source) is given by

$$\Delta T = \int \int T_s(\phi, \theta) G(\phi, \theta) d\phi d\theta / 4\pi \quad (4)$$

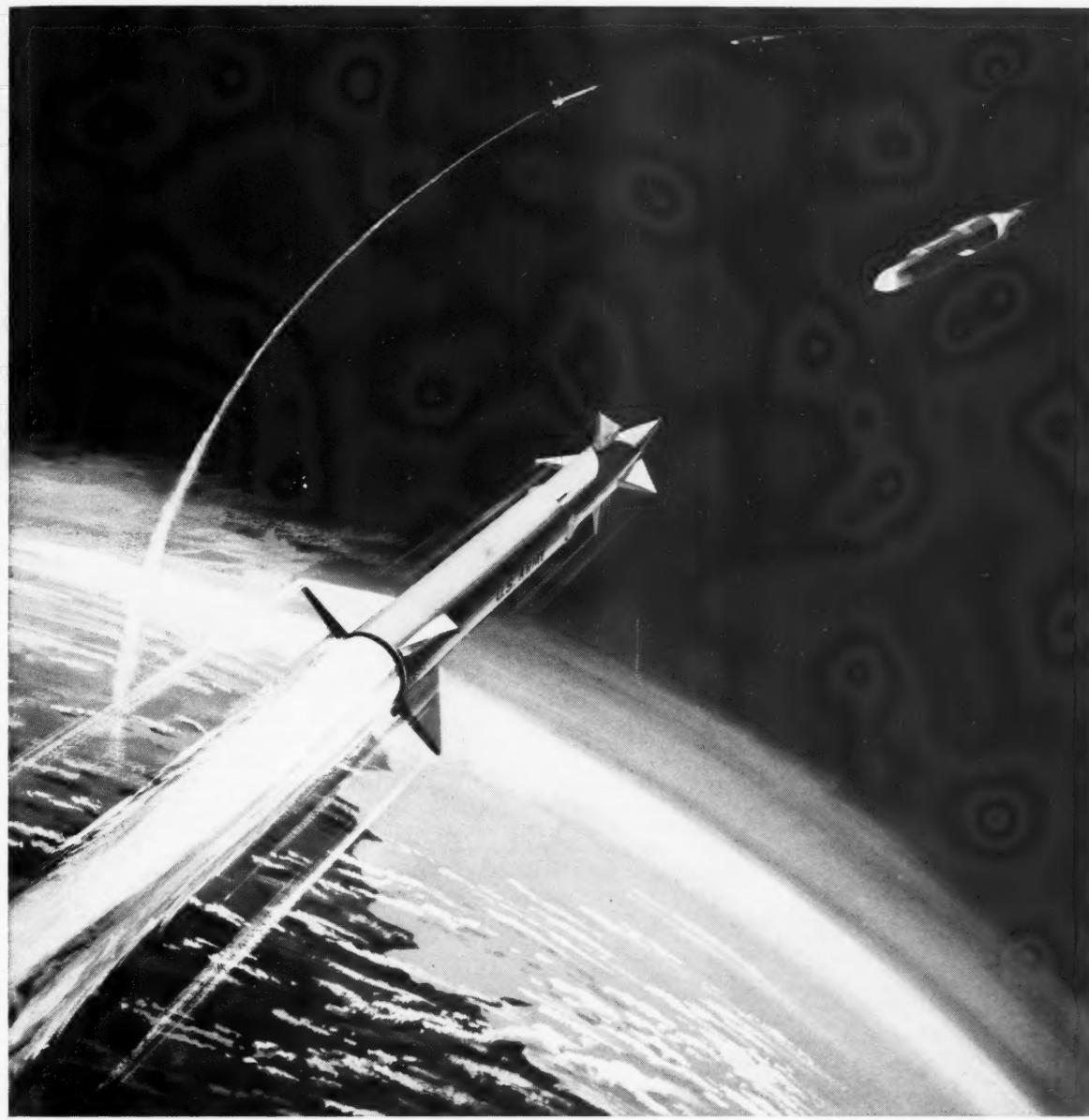
where ϕ and θ are angular coordinates and where both the source temperature T_s and the gain G are functions of these coordinates.

Conventional receivers generate a considerable amount of internal noise, noise which has an equivalent temperature of about 2000 K. Parametric-amplifier receivers have an equivalent temperature of about 100 K; masers have an equivalent temperature of about 10 K. Noise external to the receiver has a temperature which is a strong function of frequency, as indicated in the second graph here. Not shown there is one further external source of noise, the black-body radiation of the earth. This source is relatively constant with frequency. The amount of noise from this source which enters the receiver is a function of the sidelobe level of the receiving antenna (assuming that the main beam is not pointed even partially into the ground). Antennas whose sidelobe levels are low accept much less of this noise than antennas whose sidelobe levels are high. The former antennas are called low-temperature antennas, and are characterized by equivalent temperatures of from 10 to 20 K. (A typical well-made parabola and feed has a temperature of about 100 K.) Including the antenna and the maser receiver together, receiver-antenna systems of 30 K temperature are perhaps achievable in the future, whereas systems of just a few years ago were capable of little less than 2000 K.

The total noise power in the link is the sum of the external noise described in the second graph here and the receiver-antenna system noise. Two cases are illustrated in the graph on page 46, the first case using a conventional 2000 K receiving system. The over-all effects of the use of masers are to encourage the use of higher frequencies and to discourage pointing the ground antenna within 10 deg of the horizon.

Atmospheric noise increases significantly as the antenna points closer to the horizon (more of the atmosphere traversed), an effect much more important for a maser system than for the earlier 2000 K system. In addition, as the antenna points closer to the horizon, the first sidelobes intercept the black-body radiation from the earth and contribute a further increase (50 K anticipated). Consequently, space communications near the horizon will be degraded, relative to communications above a 10-deg elevation angle, by as much as 6 db for maser systems. The consequences are not serious for deep-space probes, inasmuch as the total time during which the communications are degraded is comparatively small. The consequences for low-altitude-satellite communications are much more serious because the satellites spend proportionately more time near the horizon.

A further source of external noise



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is the noise from the sun, the moon, and the planets. Of these sources, the sun is by far the strongest, and the space communicator's only hope is to avoid it whenever possible. Avoiding the sun with a maser receiver (equivalent temperature of 30 K) generally means pointing the antenna sufficiently far away in angle so that neither the main beam nor the first sidelobes intercept the sun. If the main beam of the antenna were pointed directly at the sun and if the beamwidth of the antenna agreed with the angular diameter of the sun (0.15 deg), then the temperature would be 300,000 K at 500 mc, decreasing to 30,000 K at 5000 mc (see the appended list of references). If the sun were in the first sidelobes of a typical antenna, the respective temperatures would be 1000 and 100 K. Therefore, whenever the direction of the probe from the earth is within about 5 deg of the sun, space communications with masers will be seriously degraded.

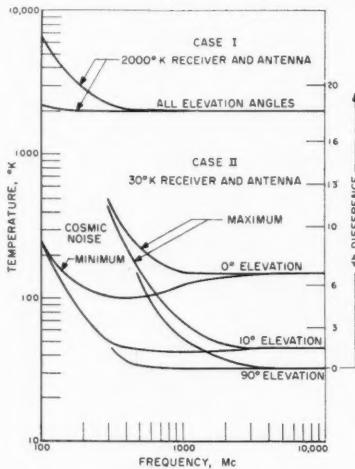
The noise temperature of the moon is between 200 and 300 K; but the moon presents a different problem, because to accomplish communications with a lunar probe (orbital or landing) the antenna performance must look directly at the moon. With ground antennas of the gains discussed earlier, the width of the main beam is comparable to the angular diameter of the moon. Consequently, the contribution of the moon's temperature (about 300 K) to the system temperature depends upon the ratio of the angular diameter of the moon (0.5 deg) to the beamwidth of the antenna ($\Delta\theta$ deg to

3 db points). Assuming that the moon is in the center of the beam, the temperature increment is

$$\Delta T = 75/(\Delta\theta)^2 = 2.8 \times 10^{-3} G_{max}$$

providing $\Delta\theta$ lies between 0.5 and

System Temperature vs. Frequency



20 deg (gains between 10^2 and 10^5). For smaller beamwidths (higher gains), the temperature is given by the temperature of the moon.

Planetary temperatures in the frequencies of interest are all less than 1000 K. More important, the angular diameters of the planets are so small that the average temperature within the main beam is low. The apparent temperatures of Venus and Mars, for example, are the following:

Planet	Source Temp K	Apparent Temperature
Venus	650	less than $0.26/(\Delta\theta)^2$ or $10^{-5} G$
Mars	300	less than $0.75 \times 10^{-2}/(\Delta\theta)^2$ or $3 \times 10^{-7} G$

where $\Delta\theta$ and G are the antenna beamwidth and maximum gain, respectively.

The range at which communication is feasible depends on the ratio of received power, P_r , to interference power in the information bandwidth Δf . A ratio of unity is defined as "threshold reception." A ratio of 10 is noisy but usable. The threshold reception range for space-earth communication (the weakest link in an earth-space-earth system) is given by

$$d = \sqrt{P_r A_t G_r / 4\pi k T \Delta f} \quad (5)$$

The usable range is approximately one-third of this value. Generally speaking, immediately available electronics limit two-way space communication to within the solar system (10^{10} mi). The nearest star is 10^{14} mi away.

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Rendezvous in Space

(CONTINUED FROM PAGE 22)

clear machine), two liquids would have to be transferred, with a probable tripling or quadrupling of the difficulties. Pressurizing gases might have to be replenished in a similar manner, which would mean the use of high-pressure couplings.

It may be argued that, if we are smart enough to establish a rendezvous technique, we are smart enough to design and fabricate such mechanical devices. A review of our missile problems seems to show that it is these mundane mechanical things that muck up the picture, rather than the grander and more glorious concepts of advanced guidance systems, radars, great structures, and very cunning materials.

It is most expensive in terms of propulsion to play a hide-and-seek game in space; a rendezvous should be established with the least expenditure of energy. This requires sophisticated

ground tracking, with the ephemeris of the "working" satellite accurately established and the "seeker" satellite fired at a propitious launch time with proper guidance and control to effect a minimum transit time. It is possible, of course, to carry the optimum launch time and minimum trajectory idea too far and place an undue strain on the ground-support and the guidance and tracking systems.

The question of guidance of the ascending vehicle for purposes of rendezvous is perhaps the overriding one. Various articles, indicated in the appended references, have been written showing schemes for ascent "rendezvous guidance," ballistics or missile type of homing guidance, and variations of such schemes. It is certain that the guidance system must fall into two major phases, the first being the proper launch time and trajectory in relation to the existing satellites, and the second being the homing guidance to be applied during the latter part of

the rendezvous undertaking. It is certain that with "operational" launch vehicles (it is assumed that a rendezvous technique is applied only when reliable operational vehicles are at hand), the initial guidance conditions can be met fairly easily. Obviously, the more precise the launch trajectory, the less exacting is the demand on the closure or homing guidance system.

This would be followed, in turn, by a lesser demand on the terminal propulsion system. The rendezvous vehicle should preferably be in a flight path that is in the same plane as the satellite to be refueled. It would also be desirable to have rendezvous effected with a vehicle that is in a circular orbit. Some authors have suggested that with the proper guidance techniques the vehicles need not be in co-planar orbits nor need they be in precise circular orbits. However, if a guidance system accurate enough for a rendezvous can be developed, surely precise circular orbits

can be established as well as co-planar orbits.

An interesting question arises as to whether the ascending vehicle alone or both vehicles should be under ground control, and during what phase of the maneuver. While an inertial guidance system with its great accuracy could launch the ascending vehicle to a very precise point in space and a very precise orbit, there is little doubt that the later phase of the guidance requirements for closure-rate control will demand either a form of feedback intelligence from the ground, or, preferably, intelligence from the existing orbiter. As the two vehicles draw closer, guidance and closure information can be obtained by Doppler radar or similar schemes; infrared or other optical controllers may be developed that will give the requisite accuracy during the last 1000 ft or so of the rendezvous maneuver.

The guidance requirements for a friendly rendezvous are simpler than those needed for some such military purpose as intercepting a "dark" satellite or "unfriendly" satellite. The orbiting "passive" satellite can carry homing or beacon equipment that would considerably ease the task of location by the transfer vehicle. Indeed, there is little doubt that the present state of the art would permit an immediate initiation of rendezvous projects if homing guidance alone were the major technical consideration.

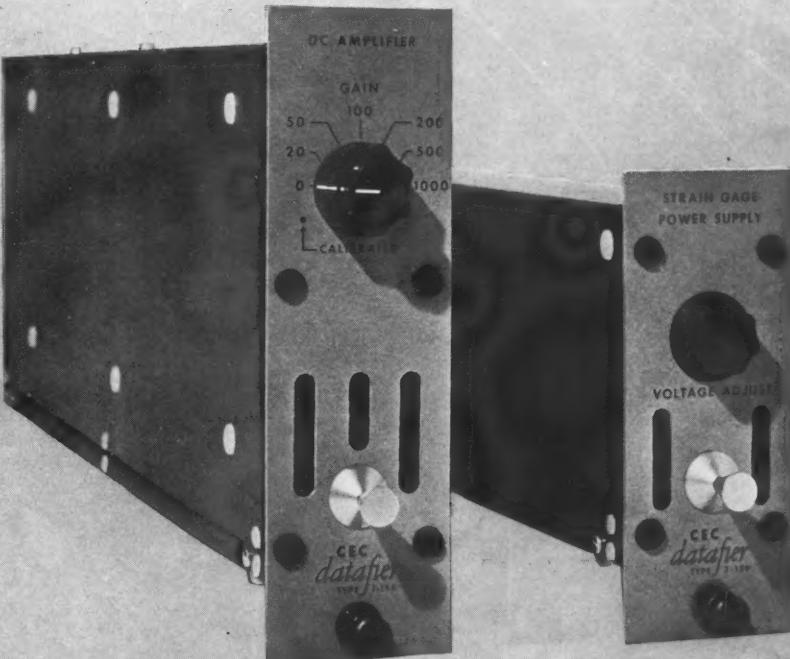
It is the maneuvering during the last portion of the maneuver, say about 1000-2000 ft, that will place the greatest technical strain on the situation. Every slight change in velocity by either the passive orbiter or the transfer vehicle will mean small changes in the orbits, either one or both, and even changes in attitude can have an effect. The closure rate must be such that no undue momentum is built up. The final contact must be feather-like. During one of the flights of Vanguard, there was an unwanted rendezvous, in that the last stage "burped" or "puffed" after burnout and bounced against the previously separated satellite. This did not benefit that latter device.

It is a considerable act of technical faith to presume that orbital coupling must, or should, be done in one pass around the earth, as some writers have suggested. It is also too much to expect that the ascending transfer launch vehicles can be launched within a few minutes or seconds tolerance for the most optimum transfer path and rendezvous. It should be possible to ease the burden on launch facilities and requirements considerably by adding to the rendezvous concept a very high-energy propulsion system that

(CONTINUED ON PAGE 50)

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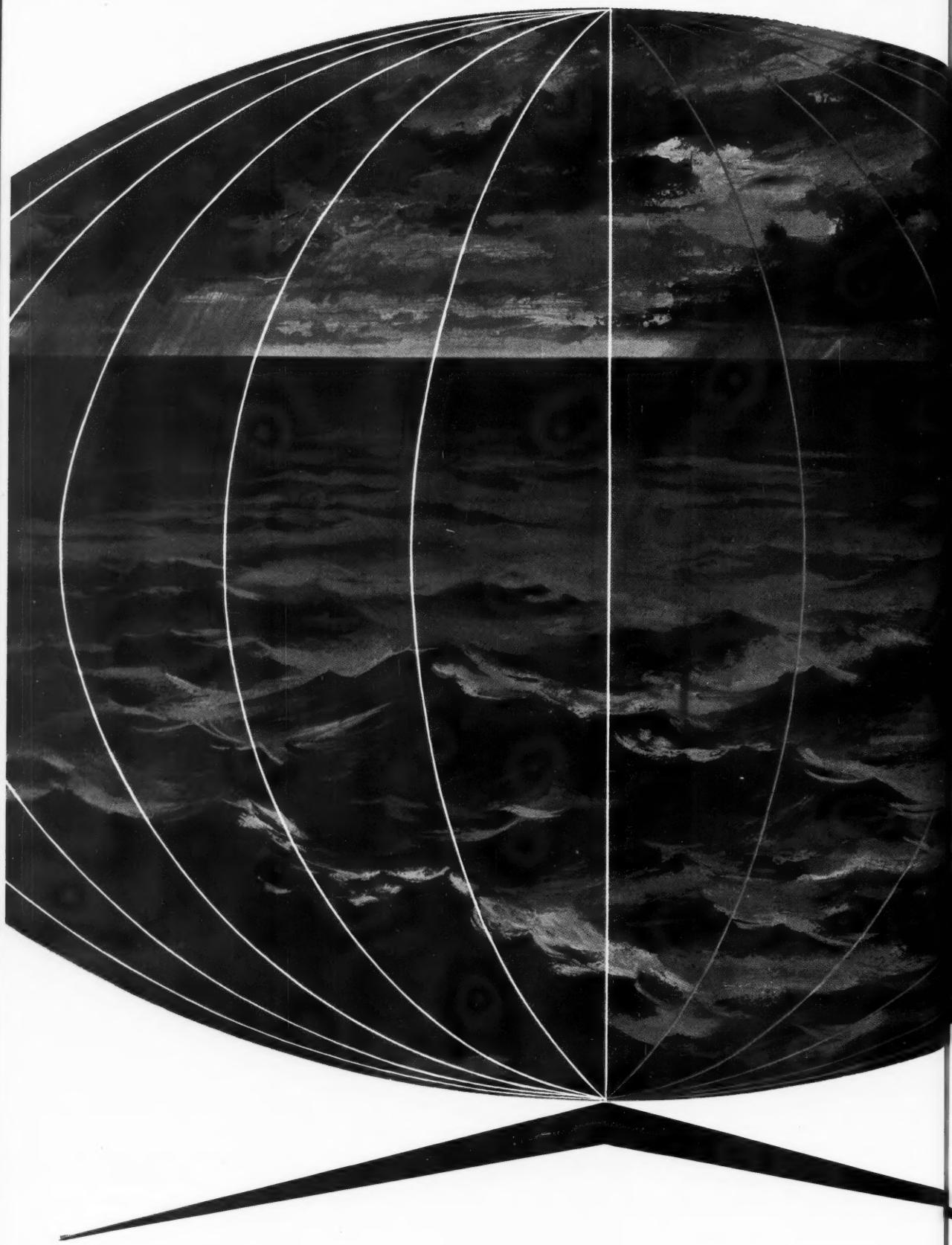
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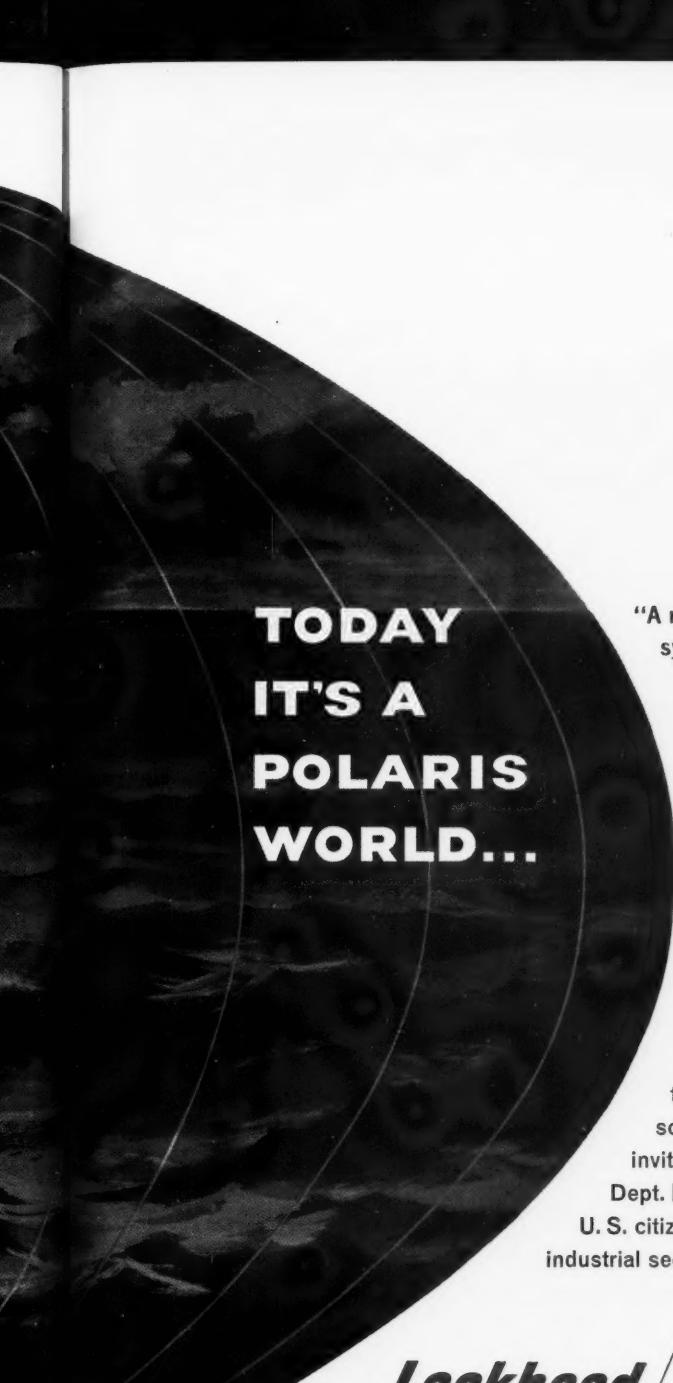
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would permit considerable in-flight maneuvering and time for closure. The electrical propulsion system would seem to fit the picture, not only because of its very high specific impulse but also because of its intrinsically low thrust, therefore low accelerations.

When it comes to propulsion, it will probably be simpler to have the orbiting vehicle completely passive and the ascent vehicle active. As stated before, the last bit of the closure will be most difficult, and such elements as the attitude-control system will require a sophistication of design and imagination unheard of. The attitude of the ascending "seeker" and the orbiting rendezvous vehicles must both be correct to very small limits of tolerance. It is probably within the duties of the ascending seeker satellite to correct not only its own attitude but that of the orbiting rendezvous vehicle, if these are far apart in attitude. If the seeker vehicle has an attitude close to what is needed, the orbiting vehicle might not need correction.

Now for the actual method of coupling. If, as stated earlier, propellant replenishment is the main purpose, then we face the situation of either coupling pipes and hoses and other connectors to the empty tankage of the orbiter spacecraft, of coupling an entire propulsion system to a spacecraft, or of building up the propulsion capability by some other stratagem, such as parallel connection of solid rockets.

The transfer of liquids in a weightless environment involves, again, exact attitude control and the application of small G forces or other means to give some head to the propellants. These factors do complicate the picture. It would be simpler to couple an entire propulsion system, tanks and all. Even if the simplest of connector joints were designed for propellant transfer and simple mechanical latches for the spacecraft, electrical couplings would still have to be provided. The writer has yet to see, from past experience or future expectations, any electrical joints for rocket purposes that are designed for quick, easy, and reliable connection or disconnection. Therefore, a good scheme might be the inductive coupling of the spacecraft to the connected propulsion system.

There is no technical reason why several hundred channels of wireless information links could not be inductively coupled to the attached propulsion system. All operations of guidance control and propulsion control could be then achieved from one spacecraft.

The actual physical connection could be achieved by magnetic plates which would draw the two vehicles together during the last few inches

and make an immediate fit, so that mechanical latches could be actuated more or less as an afterthought rather than a primary operation. Of course, if the propulsion tankage and system (empty) is a part of the orbiter, then no such scheme is required, although for propellant replenishment some electrical connection might be necessary. It is, under any circumstances, a good rule to eliminate as many moving clamps and connectors as possible.

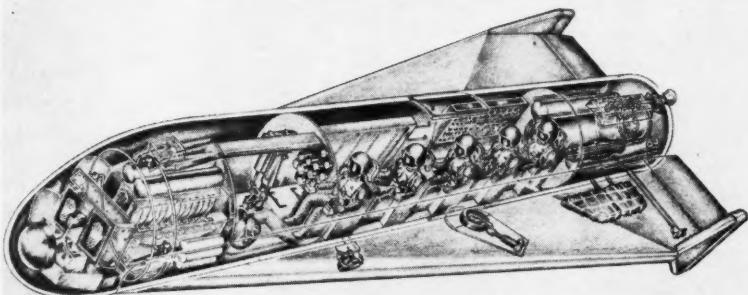
The nuclear rocket offers certain economic and technical benefits for rendezvous. An expensive reactor that may have a lifetime longer than that needed for its original propulsive purpose can be reactivated and used again for escape from orbit (if that is what is required) by the relatively simple act of replenishing the working fluid, probably hydrogen. This does not mean to say that transferring a

cryogenic fluid such as liquid hydrogen is in itself intrinsically simple, but at least one propellant only is used and the arrangement of connectors and piping and plumbing is thus simplified.

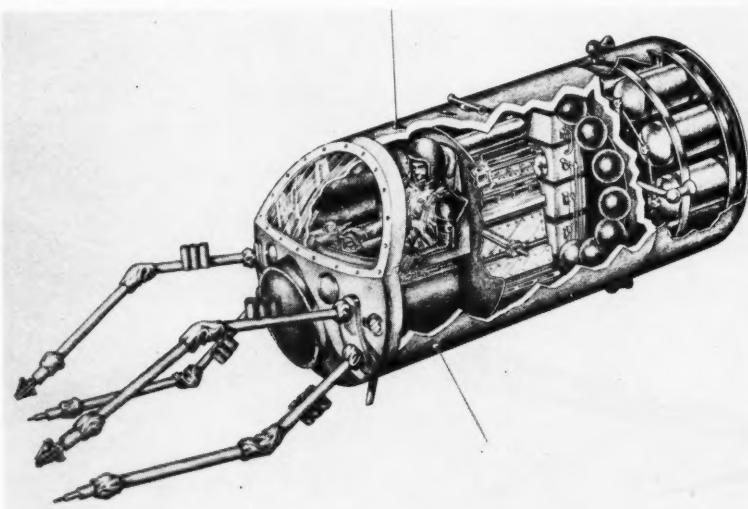
The solid-propellant rocket offers certain advantages for the coupling of a propulsion system, since the behavior of weightless liquids is avoided and the ignition startup and firing sequence is simpler than for a liquid system. It is possible to foresee orbiting propulsion replenishment or addition done by launching solid-propellant refuel units that are propelled by electric engines or gas jets which provide propulsion and control. It may even be possible to assemble additive elements of solids by parallel clustering, or even by some type of quick grain segmentation, although that is probably a most difficult task technically.

At any rate, orbital refueling or

Air Force Starts Orbital Rendezvous Studies



Space vehicles of this kind—above, design study of five-man shuttle for rendezvous and then glide return to earth and, below, tug for assembling space station in orbit—are included in one Slomar (Space Logistics, Maintenance, and Rescue) study program being conducted by the Martin Co. under a \$14,000 Air Force (WADD) contract. The whole Slomar study covers Air Force needs over the next 15 years or so.



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replenishment seems technically to be simpler if an entire loaded and assembled propulsion system (whether that be a solid or a packaged liquid) can be coupled to a spacecraft.

The technical problems, then, of orbital rendezvous for refueling are tremendous ones.

First, they center about the coupling of vehicles by some form of robot action, unless men are in the spacecraft to be replenished, in which case some manual manipulation is possible, but even there the possibilities are limited. Robot coupling might be aided by ground-based television monitoring.

Second, with the orbital spacecraft or vehicle to be replenished having "active" homing beacon equipment, the problems of interception are much reduced for the ascent vehicle. Surely there exists presently enough knowledge in that electronic area to permit already some form of simple rendezvous technique; the procedures that remain to be worked out are those of the "localizer" approach for final coupling.

Third, the development of high-energy propulsion systems will ease the demand on guidance and control units, so that several orbital passes and approaches may prove feasible, permitting enough time for proper orientation of the vehicles vis-a-vis each other.

Fourth, the coupling of entire propulsion packages to the spacecraft that is in orbit would seem to be preferable to replenishment by loading liquids, although there are enough problems of launching an entire propulsion package by one ascent firing.

Fifth, anything that can be done to ease launch-time requirements by the ascending vehicle will prove to be an economical measure, since, at least in the foreseeable future, no magic is available to launch large rockets within a desired few-seconds span.

Sixth, the need for optimum flight paths and transfer ellipses, etc., while desirable, could be subordinated through the use of a high-energy propulsion system.

Seventh, rendezvous for the purpose of replenishing a space station may actually not be a more complicated process than refueling, since discrete objects would be passed from one vehicle to another, including men, food, and oxygen. This would require the development of airlocks and other safe coupling mechanisms which would permit men and stores to leave a space station and enter another.

As space technology progresses, the use of partially self-sustaining space stations should prove a technically desirable undertaking. Anything that

can be done to lessen requirements for supplying food and oxygen will ease rendezvous launch-vehicle requirements. The writer has not treated this aspect of rendezvous to a great extent, since "permanent" manned space stations may not be an immediate and urgent space task for this country, in contrast to unmanned and manned lunar landings and planetary explorations.

But it can be said that manned space stations, if these became a space objective, would provide a powerful motivation for the development of rendezvous techniques. Surely no attempt would be made to initiate a space-station development without a parallel effort on rendezvous and ferry concepts. Thus, if remote-control orbital refueling becomes an established technique within the next decade, then the somewhat simpler task of space-station life support and personnel transfer can follow without much further development.

Also, it may be possible to establish small three-to-six-man permanent space stations without having an equal capability for a three-man lunar landing and return vehicle. But the necessary space-station rendezvous technique would pave the way for the much more difficult lunar attempt.

Finally, the economic justification of rendezvous will prove a powerful motivation. Some cost estimates are

given on page 22.

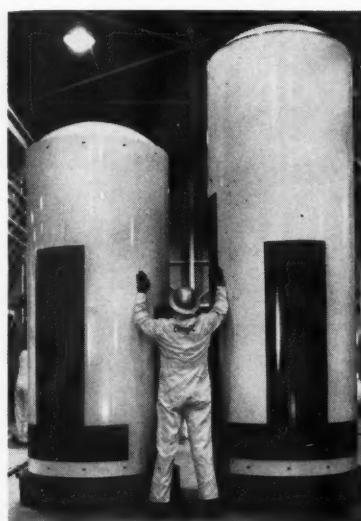
As stated earlier, there may come a time when vehicle size can no longer be increased practically. It is most probable that rendezvous techniques or ferry projects will then be a definite and necessary part of our space technology. Space rendezvous will depend on the use of proven rockets and components. There seems little question of the feasibility of the technique. Once it is established, it will add an otherwise unattainable dimension to space exploration.

For the immediate present, while no preliminary development testing can take the place of an actual orbital-rendezvous attempt, some testing, at least, should be possible for docking-technique development. It might be possible to suspend buoyant scale-model seeker and target vehicles below surface in water tanks with control exercised through sonic "telemetry." Actual propellant transfer might even be possible, with the vehicles propelled and stabilized just as in space. Something could also be done with airborne apparatus, with all guidance and control functions programmed into the carrier vehicles.

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More Power for Polaris

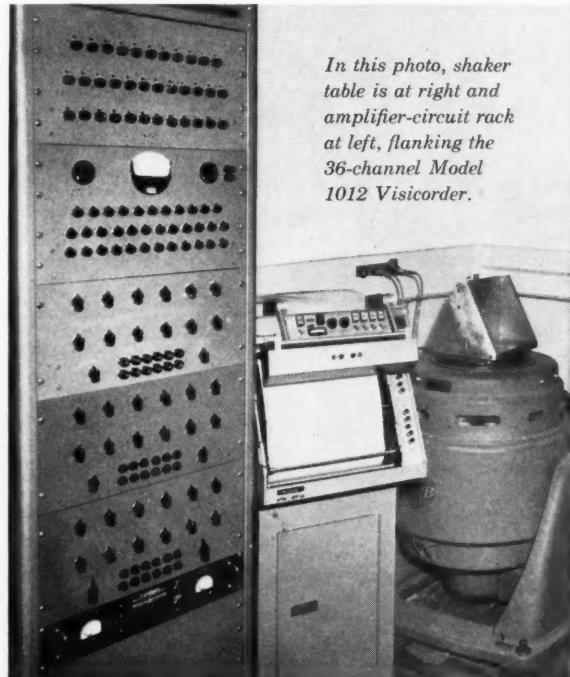


A-1 and A-2 Polaris boosters, left and right, respectively, show the size differential that corresponds to missile's increase in range from 1200 to 1500 n. mi. Aerojet-General developed and produces both solid-propellant motors for the Navy.

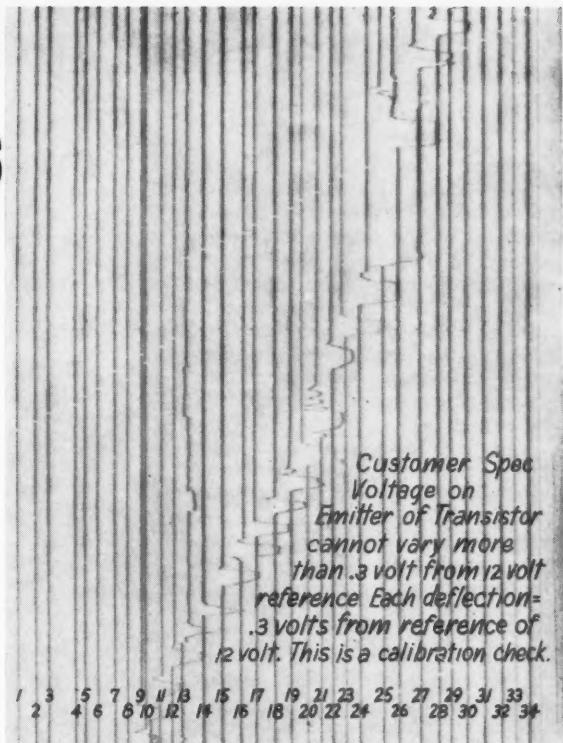
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In this photo, shaker table is at right and amplifier-circuit rack at left, flanking the 36-channel Model 1012 Visicorder.



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By Irving Michelson, Illinois Institute of Technology

ASTRONAUTICS is now big business and, like many big businesses, has spread to every section of the country. As a result the career-minded aeronautical engineer or scientist is today in a position to find positions to his liking in the North, South, East, or West, and is not limited to one particular area but can choose among locations virtually a continent apart or at many stopping points along the way.

The South especially is going through a period of great industrial expansion, and the aeronautics industry has moved into this area in force. Some businesses have moved South virtually lock, stock, and barrel; other companies have opened subsidiaries in the Southern states; still others have started from scratch. The attractions are many. Land, labor, and taxes are relatively lower than in other sections of the country; a good climate, a more tranquil way of life, and the heritage of our founding fathers often represent additional plus factors.

Virginia, the Old Dominion, may be taken as an example of the blossoming South. The state's aeronautics industries extend northward virtually to Washington, D.C., and to the suburb city of Alexandria where up-and-coming businesses abound.

One of these is CEIR, Inc., whose business lies in providing machine (electronic) computations, including development of programs, for any organization (in space or otherwise) in need of such aid. Its Space Technology Div. is working on trajectory analysis and development of survey and guidance theories for interplanetary navigation. It is also concerned with space economics—for example, optimum use of the resources in a space vehicle and the real costs to achieve a specified space objective. The company's growth has been dynamic, as attested by about a 25-fold increase in the cost of its stock in less than a year. Apparently, its employees are from all the disciplines, including economists, mathematicians, statisticians, physicists, chemists, etc., as well as formal programmers.

Another Alexandria industry is Atlantic Research Corp., whose stock appreciation almost parallels that of CEIR. About 60% of its effort is related to solid propellants, which it both develops and manufactures. The company also does basic research in kinetics and rocket combustion. More-

over, its interests include electronics, communications, plastics, materials research and testing, optics, pyrotechnics, and dehumidification. Currently, it has needs for trained scientists in virtually all fields with at least five years experience.

Less than 100 air-miles south of Washington, in Richmond, is Texaco Experiment Inc. Its business comprises all aspects (fundamental and applied) of propulsion development, including liquid and hybrid rockets and air-breathing powerplants. It recently became a part of Texaco, Inc. and intends soon to expand into production of novel air-breathing systems. The TEI air-turborocket, it firmly believes, is more than competitive with rockets as a boost vehicle. Also, as part of the Texaco team it shares the largest AF contract yet awarded to uncover and synthesize superior liquid-rocket propellants—a real blue-sky effort. It is expanding from a nucleus of a little more than 100 as rapidly as it can find capable people, with the sky the limit. (The professional staff has grown over 40% in less than a year.) TEI is currently seeking experienced chemists and physicists, and mechanical, aeronautical, and electronic engineers.

In the extreme East, or Outer-Banks area of Virginia, is the NASA installation at Wallops Island from which Scout satellites are orbited. And, further south near Norfolk, is the great, sprawling NASA Langley Research Center. Langley, of course, needs no introduction. Its enviable accomplishments as part of NACA are history. Under U.S. Public Law 85-568, as part of the newer NASA, it is now charged with providing "research into problems of flight within and outside the earth's atmosphere," except activities associated with the military. Its facilities represent an investment of \$150 million on a 710-acre location with 1100 professionals and 2100 supporting-staff members. There is probably no field in all of the Sciences which is not covered in some manner by the work at Langley. Those with a leaning for the Civil Service way of life could probably contribute no more anywhere than at Langley.

An electronics organization in Leesburg which expects to expand in the near future is Development Engineer-

ing Corp. This company designed the Navy's moon relay system, was part of the team that designed the world's most powerful radio telescope, and has demonstrated communication by radio waves sent through the earth. It has expanded its volume of business nearly 100-fold in the past eight years, opening subsidiaries in Colorado and Massachusetts. DECO is seeking high-caliber people in the field of advanced communications and antenna design and development.

So, briefly, career opportunities beckon in the South. The barest minimum have been mentioned, and these only in the single state of Virginia. The career-minded, then, would do well to consider the area which in our nation's infancy not too many years ago produced the best of which America is capable.

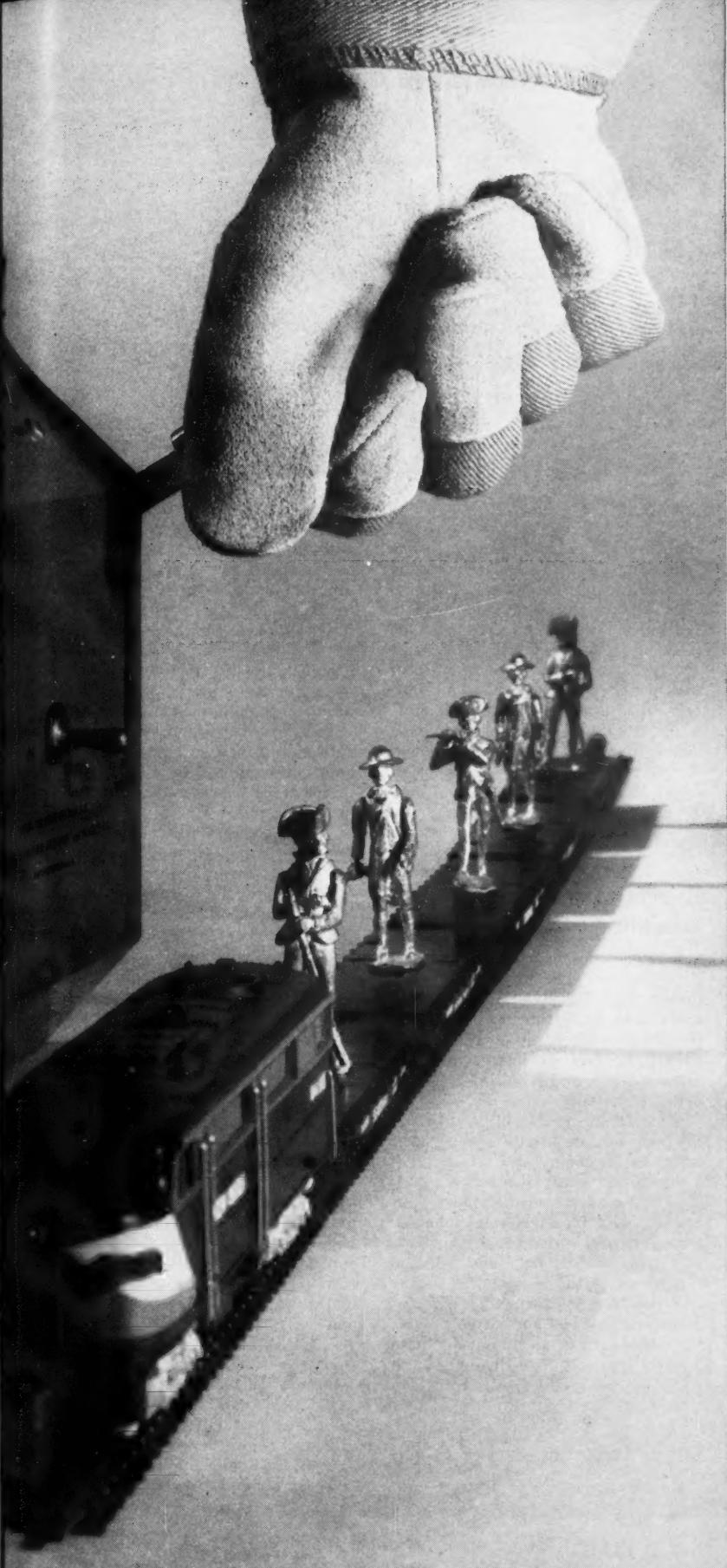
For specific career opportunities, see 2nd cover, pages 2, 9, 13, 18, 48-49, 69, 73, 75, 77, 83, 85. ♦♦

Japanese Officials on Tour

Last month, nine officials prominent in Japan's space-science programs visited the NASA Marshall Space Flight Center in Huntsville, Ala. Members of a Japanese Survey Mission for Space Science and Technology—who will also visit Canada, the United Kingdom, France, the Federal Republic of Germany, and Switzerland—the officials will study the present status and trend of space science and measures for international space cooperation.

Kankuro Kaneshige, chairman of Japan's National Space Activities Council, heads the Survey Mission. Other members include Noboru Takagi, professor of electrical engineering at the Institute of Industrial Science, Tokyo; Fujio Nakanishi, director of the National Aeronautical Laboratory, Science and Technics Agency; Shojio Nanbe, director of the Research Institute of Kokusai Danshin Danwa Co., Ltd.; Masaji Miyaji, director of Tokyo Astronomical Observatory, Univ. of Tokyo; and Tetsuya Senga, councilor of the Federation of Economic Organization.

Also, Tabayoshi Murao of the Planning Bureau, Science and Techniques Agency; Masao Yoshida, chief of the Nuclear Material Section, Japan Atomic Energy Research Institute; and Shozo Shimomura of the Budget Bureau, Ministry of Finance.



He's got Minutemen "working on the railroad"

Hard basing is one way to protect America's force of retaliatory ICBM's. The problem was to find an alternate means of accomplishing the same mission. The Air Force solution was a new ICBM mobility concept—railroad car-mounted Minutemen, utilizing the nation's vast track mileage for numerical and geographical dispersion, creating a difficult target for enemy attack.

To put the Minuteman, its support systems and associated equipment on rails was a completely new problem in missile handling. The first requirement assigned by Boeing to American Machine & Foundry Company and ACF Industries, Inc., was a feasibility study of the existing limitations of roadbeds, rails, railroad operations and right-of-way. Unique tactical cars are being designed within these limitations to carry the Minuteman—cars that can handle the missile and its operating equipment, safely isolated from roadbed shock and ready for immediate retaliatory launching.

Single Command Concept

Whether for conceptual problems such as this one, or for challenges in design or manufacturing, AMF has ingenuity you can use. AMF people are organized in a single operational unit offering a wide range of engineering and production capability. Its purpose—to accept assignments at any stage from concept through development, to production, and service training...and to complete them faster in

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Tungsten-Base Composites

(CONTINUED FROM PAGE 36)

materials development.

Avcomet contains, other than tungsten, a material that in comparison has a lower melting point and lower vaporization temperature. The surface temperature of the composite material stays lower than that of pure tungsten under intense heating because of the latent heats of melting and vaporization of the second material in the composite and because of the transpiration effect of the vaporizing material. The sum of these two phenomena is not unlike ablation. The important difference is that a nozzle-throat area remains relatively unchanged while this material releases its heat of vaporization and transpires into the boundary layer.

This performance has been the subject of both theoretical analysis, with the aid of digital computers, in something like the manner of Avco's pioneering computer analyses of ICBM nose cones during the past several years, and of experimental studies.

For example, a particular composition of Avcomet was analyzed with the aid of an IBM 704 computer and its performance was compared with pure tungsten's. Both the Avcomet and the tungsten were taken to be in the form of $\frac{3}{8}$ -in.-thick sheet backed by $\frac{1}{8}$ -in.-thick graphite sheet and reinforced with an insulating back. The gas flow acting on the experimental specimens was modeled on that typical of a second-stage Minuteman rocket engine.

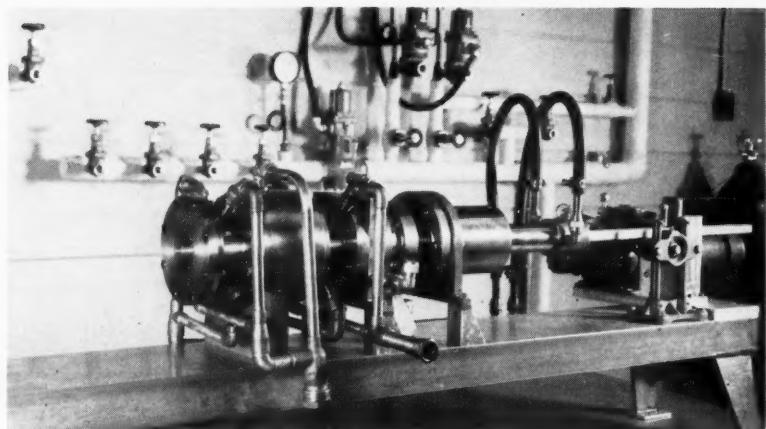
The table at bottom shows in summary form the histories of surface temperature vs. time that this analysis gave. The Avcomet shows a temperature lag of nearly 600 F under steady-state conditions (after about 20 sec) compared with pure tungsten.

A more palpable demonstration can be made with a plasma generator, such as that shown above right, an Avco Model 500 (500 kw) arc-plasma generator with these characteristics: Power level, 100-1500 kw; air-mass flow, 0.005-0.04 lb/sec; chamber pressure, 1-10 atm; enthalpy, 3500-12,000 Btu/lb; and throat diameter, 0.25-1.0

Calculated Surface Temperature

Time (sec)	Surface Temperature (F)	
	Avcomet-1	Tungsten
1	1920	1920
2	2720	2720
5	3600	3900
10	4460	4660
20	4660	5240
40	4680	5280

Avco Model 500 Arc-Plasma Generator



in.

Such tests have been made to compare Avcomet-1 and pure tungsten. Nitrogen was used as the working fluid to minimize oxidation of test samples, examples of which subjected to the arc jet for 60 sec are shown on page 36. The enthalpy (H/RT_0) of the gas was about 100 and the heat flux was approximately 750 Btu/ ft^2 sec. Neither of these samples melted.

But at higher enthalpies and heat fluxes—for example, $H/RT_0 \cong 200$ and flux of 1280 Btu/ ft^2 /sec—the superiority of the Avcomet-1 clearly appeared, as can be seen from the photo on

page 36. The pure tungsten melted within 30 sec but the Avcomet-1 did not melt after even 60 sec.

Avcomet-1 appears to be the best tungsten-based composite developed to date. It has been successfully tested at two solid-propellant-rocket development facilities in motors with chamber pressure of 1000 psia for 60 sec. Further work on Avcomet compositions are in progress.

It is our conclusion from work to date that tungsten-based composites hold considerable promise as a high-performance nozzle material now and in the future. ♦♦

Holloman Summer Scientific Seminar Scheduled

Holloman Summer Scientific Seminars will be held in the two-week period June 19-30, 1961, at Cloudcroft, N.M. The topic will be Astrophysics and the program will present Eberhard Hopf in five lectures on ergodic theory and R. S. Richardson in five lectures on celestial mechanics.

Two lectures each will be given by ten other leading scientists on as many topics of astronomy and astrophysics. These speakers are Otto Struve, Donald H. Menzel, Gerald P. Kuiper, Carl Sagan, Seth B. Nicholson, John D. Strong, Herbert Friedman, N. U. Mayall, John D. Kraus, and George Gamow.

A day-by-day calendar of the program is available and arrangements for attendance to all or any of these lectures may be made by writing to Dr. J. R. Foote, P.O. Box 1053, Holloman AFB, N. M.

Strain Gage Course Set at SRI

An intensive short course in strain-gage techniques, co-sponsored by

Southwest Research Institute and the Society for Experimental Stress Analysis, will be given in San Antonio, Tex., April 17-21. Lecture tuition is \$175, laboratory \$100 more. Applications and tuition must be in the hands of Dr. M. M. Lemcoe, SRI, Box 2296, San Antonio 6, Tex., by April 10.

New Timing Broadcast Aids Astronautics

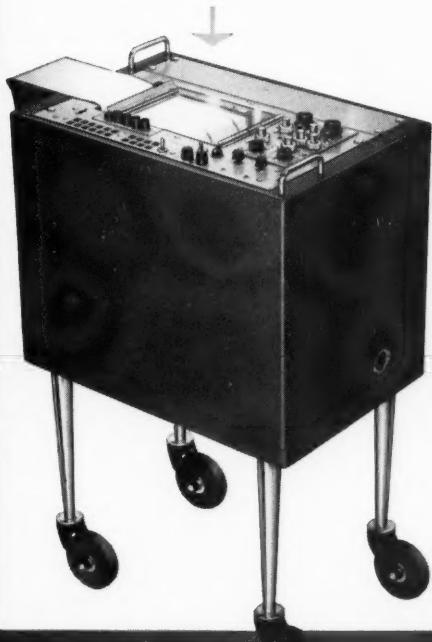
In January (0000 UT) the National Bureau of Standards retarded the time signals broadcast from radio stations WWV and WWVH by 5 millisecond, bringing them into closer agreement with other worldwide standard signals, and at the same time resumed broadcasting on WWV a special timing code that gives day, hour, minute, and second (UT) coded in binary form. This year, it is planned to maintain the frequency stable to 1 part in 10^{10} at the same offset as previously (-150 parts in 10^{10} with reference to the U.S. Frequency Standard). The new timing code provides a base for scientific observations made simultaneously at widely separated places, as in space-vehicle tracking.

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Operate this 1-cubic-foot recorder vertically, horizontally, or tilted at a 20° angle on carrying handle. Inputs are floating and guarded . . . 12 sensitivities from 0.5 mv/mm to 20 v/cm . . . response DC to 125 cps within 3 db, at 10 div peak-to-peak . . . max. non-linearity 0.25 mm . . . common mode rejection 140 db min. DC . . . built-in 10 mv calibration signal and electrical limiting . . . internal 1 sec. timer . . . monitor output connectors for each channel. Galvanometers are rugged, low impedance type with velocity feedback damping; most circuitry for each channel is mounted on a single, easily serviced card.

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... 10 mv/div DC Model . . .
10 uv rms/div AC strain gage Model

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For complete details contact your nearest Sanborn Sales-Engineering representative. Sales representatives are located in major cities throughout the United States, Canada and foreign countries.

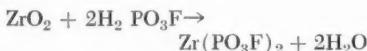
 **SANBORN COMPANY**
INDUSTRIAL DIVISION
175 Wyman Street, Waltham 54, Massachusetts

Composite Ceramic Metal

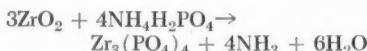
(CONTINUED FROM PAGE 29)

for the corrugated metal strip. The resultant components have successfully withstood several 20-min cycles of exposure to temperatures of 3500 F.

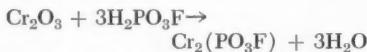
To extend this concept to higher operating temperatures, zirconia was selected as the most likely candidate material to produce composites that successfully withstand exposures to 4400 F for extended periods of time. Time-stabilized zirconia, Type H (cubic crystalline form), was selected for the application. As in the alumina-base composite, a phosphate bond was used by providing phosphate radicals from acids and salts. The primary bonding was obtained by using monofluorophosphoric acid according to the following equation:



In order to retard the bonding action and increase the shelf life of the trowelling consistency, ammonium dihydrogen phosphate was added to the composition and reacted in the following manner:



An additional constituent, chromia, was added to improve the workability of the consistency and increase the emissivity. It reacted in the following manner:



The composition by weight of the final matrix material was as follows:

ZrO_2 , 30F.....	80
ZrO_2 , 325F.....	5
Cr_2O_3	15
$\text{NH}_4\text{H}_2\text{PO}_4$	9
$\text{H}_2\text{PO}_3\text{F}$	5
H_2O	15

The particle distribution of the final composition contained 22.6% of particles through 60 mesh on 80 mesh and 77.4% of particles through 80 mesh on 150 mesh. The resulting bulk density was 204 lb/cu ft and the apparent porosity was 22%.

The hard, crackfree matrix developed through these reactions had excellent erosion resistance when blasted at room temperature with a constant flow of 20-grit silicon carbide. It processed the same erosion resistance as dense graphite, four times the resistance of dense 99% alumina brick, and over four times the erosion resistance of zirconia brick.

The ceramic matrix was incorporated into a reinforced-ceramic coating

system consisting of a base metal substrate of 1/2% Ti-molybdenum alloy sheet to which was resistance-welded a corrugated-strip reinforcement of 0.010-in.-thick, 0.125-in.-wide molybdenum alloy. The resistance welding was facilitated by applying a plasma-flame-sprayed chromium to both surfaces. The chromia also served to protect the molybdenum against oxidation. The welded assembly was coated with a Type 418 vitrified coating to enhance further the oxidation resistance of the molybdenum. The matrix was then trowel-impregnated into the surface. The composite was low-temperature-cured at 300 F.

The resulting system exhibited a thermal drop across a thickness of 0.250 in. of approximately 2300 F when exposed to a plasma flame on

Matrix Material Performance

Temperature F	Load Rate, lb/min	Modulus of Rupture, psi
1000	19.8*	1940
1500	19.5	1878
2000	19.9	1565
2400	13.8	543

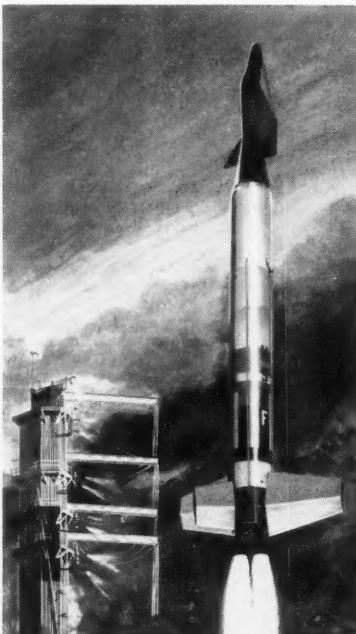
the ceramic side. The ceramic surface was measured at 4200 F while the back surface was only 1900 F at steady-state conditions. The total normal emissivity over the temperature range from 2000 to 4000 F was, nominally, 0.8 for a rough surface and 0.68 for a ground surface.

The resistance to thermal shock was determined by a series of heating and cooling cycles and by heating and water quenching. In the first test, the ceramic surface was plasma-torch-heated to 4200 F for 2 1/2 min and then cooled with an air blast at a rate of 650 F per sec to 1000 F and somewhat slower to room temperature. The composite successfully withstood seven such cycles. The photos on page 29 show the sample after testing and with the ceramic chipped away to reveal that the reinforcement was not oxidized. The second test consisted of heating the ceramic face to 4400 F, holding the temperature constant for 2 min and then dropping the sample into water. No damage was observed after two such cycles. The elevated temperature modulus of rupture of the matrix material in an unreinforced condition is given in the table above.

The great promise of this type of metal-ceramic composite has not been explored to date. It is expected that systems similar to the one described will find considerable use as thermal-barrier and structural materials in applications where temperatures above 4000 F are encountered.

Again, the specialized uses for these materials require that they be designed and engineered by the user in much the same manner as the other engineering technologies are applied to produce a weapon system. The field of metal-ceramic composites is rapidly expanding and the results of this activity should produce materials capable of operation at temperatures above 6000 F in the next two to three years. ♦♦

Titan II Slated to Boost Dynasoar

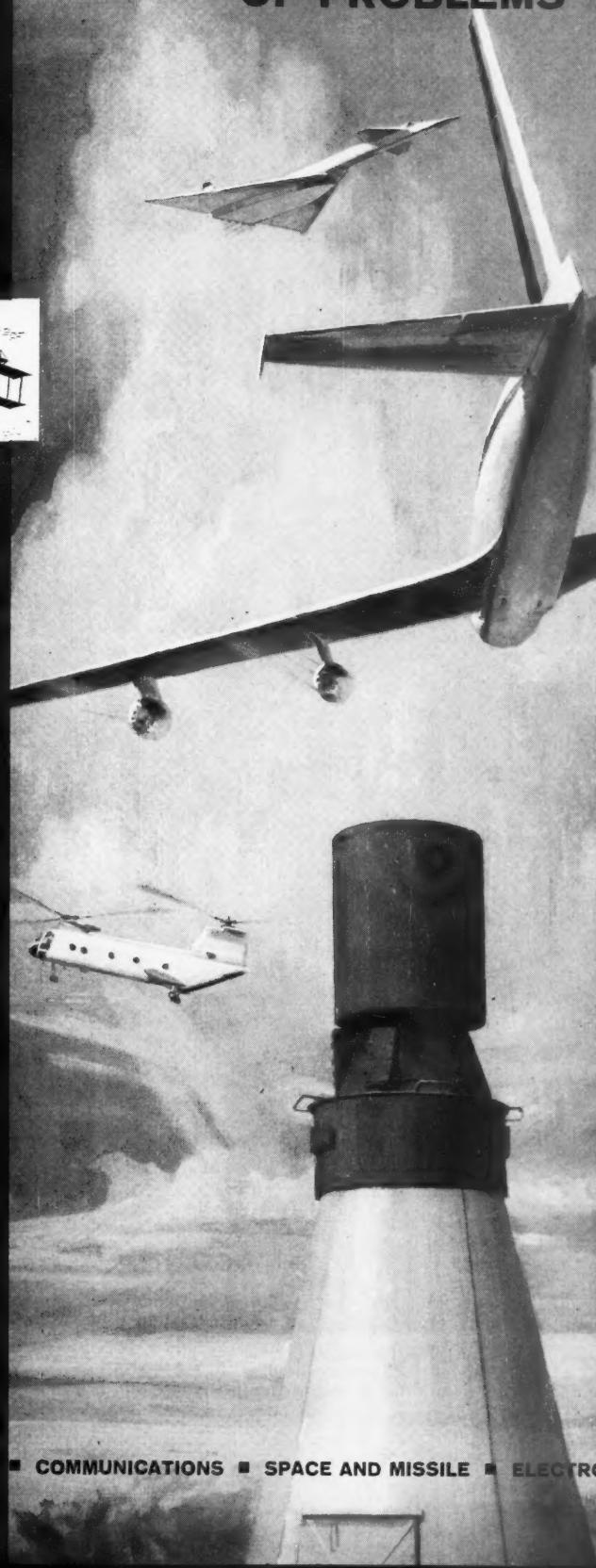


This artist's conception, developed by the Martin Co. and approved by the Air Force, depicts the Dynasoar manned boostglide vehicle as it will launch into space under power of the Titan II booster. The Titan II missile, being developed by Martin, is scheduled for flight testing within a year. Its new engines, developed by Aerojet-General, burn hydrazine-mixture fuel and nitrogen tetroxide oxidizer, a storable combination. The Air Force is pushing to bring Dynasoar to the flight-testing stage within three years.

AEC Research Summary Out

"Atomic Energy Research in the Life and Physical Sciences—1960" is now available from the Supt. of Documents, GPO, Washington 25, D.C., at \$1.25 per copy.

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ARS news

AAS Again Turns Down ARS Merger Proposal

Harold W. Ritchey, President of the AMERICAN ROCKET SOCIETY, announced last month that the American Astronautical Society has again declined an ARS proposal for a merger.

Dr. Ritchey stated that William H. Pickering, chairman of the ARS Policy Committee, had received a letter from Alfred M. Mayo, president of AAS, informing him of the decision made by the AAS Board at a meeting held recently in Dallas, Texas. A previous merger proposal made to AAS by ARS in 1959 was also rejected.

Mr. Mayo's letter states that "the Board voted unanimously to decline this merger proposal and to cease any further efforts concerned with such a merger."

The letter from Mr. Mayo then indicated that AAS intended to set up a special committee for coopera-

tion with ARS as follows: "We do, however, value highly our friendship and cooperation and hope to greatly strengthen these for our mutual benefits. To this end, I am, as the 1961 President of the AAS, setting up a special committee for this specific purpose."

Dr. Ritchey, in his announcement, expressed his regret that AAS had not felt it appropriate to merge with ARS since, he felt, "both ARS and AAS have the same objective; namely, the advancement of aeronautics."

Dr. Ritchey released the following additional statement addressed to the 18,000 members and 170 Corporate Members of the AMERICAN ROCKET SOCIETY: "Because of the widely expressed concern on the part of industry and government organizations in the missile and space field about the apparent overlap in

interests of the AMERICAN ROCKET SOCIETY and the American Astronautical Society, the ARS Board of Directors felt it appropriate to offer a proposal of merger to the AAS Board.

"The terms of the merger proposed by ARS had included a name change for the combined societies and proportionate representation of the two societies on an enlarged Board of Directors, on Technical Committees, and on Standing Committees.

"Discussions between groups representing both ARS and AAS have taken place on a number of occasions over a period of about two years and these discussions have been both amicable and cooperative. It is to be regretted, however, that they did not produce the desired results."

ARS Propellants, Combustion, and Liquid Rockets Conference Coming Up This Month

The forthcoming ARS Propellants, Combustion, and Liquid Rockets Conference, to be held April 26-28 at the Palm Beach Biltmore, Palm Beach, Fla., is being jointly sponsored by the Liquid Rocket, and Propellants and Combustion technical committees, under the general chairmanship of Charles King. While the technical excellence of the papers to be presented will insure a large attendance, the locale, Palm Beach, will simply act as the frosting.

In addition to the technical program, a field trip to Pratt and Whitney's rocket engine facilities will be arranged. A reception and banquet has also been planned, and General Don Ostrander will be the principal speaker.

Eight technical sessions have been arranged for the two-day meeting. Thus simultaneous sessions will be necessary. Both technical committees are very enthusiastic about the subject matter of the meetings, and a variety of significant papers have been submitted.

Two sessions will be devoted to the subject of detonation. With ever-greater interest being shown toward

mobile missile systems, the problem of propellant detonability has assumed great importance. A session covering this topic will be conducted under the chairmanship of Marjorie Evans. In addition, C. M. Wong will chair a session devoted to the mechanism of detonation phenomena.

Two aspects of the flow process in nozzles will be considered at this meeting. A session on Two-Phase Flow in Nozzles has been arranged by Billings Brown, and it may be expected that the lively controversy that has followed this subject will continue. From another tack, the general subject of Lag Processes in Rocket Nozzles will be discussed by a distinguished panel of experts. S. S. Penner has agreed to moderate the debate. A considerable time has elapsed since the last public discussion of this important subject, thus a very stimulating afternoon can be anticipated.

Several times in the past, attempts have been made to arrange an ARS session on the topic of Heat Transfer to Boiling or Near-Critical Liquids, with emphasis on liquid hydrogen. Always, the problem of paper clearance has prevented the presentation

of an unclassified session. However, the proper arrangements have finally been made, and W. A. Benser will introduce a group of papers covering this subject.

Finally, there will be two classified sessions devoted to two separate, but highly important, features of rocket technology. One is well known to all those connected with engine development—Combustion Instability in Large Liquid Rockets. However, this session treats the subject somewhat differently than has often been done in the past. Here the authors have been asked to avoid discussing only an idealized instability model, but to consider the actual events as observed in developmental-type combustion chambers. Furthermore, certain of the papers will discuss means that have been found effective in inhibiting unstable combustion behavior.

Another subject in the program is one which has never before been treated in an open (albeit classified) technical forum. Thus it is expected that enormous interest will be generated by the session on Radiation Characteristics of Exhaust Plumes.

F. C. Harshbarger has arranged for a series of papers that will treat with certain theoretical aspects of the problem, the characteristics of laboratory experiments, and the observations made during the conduct of static and

flight firings of large rocket engines. This subject will be of particular interest to those persons who are concerned with the problem of detecting or observing the flight of ballistic missiles.

An additional session has been arranged for the presentation of several excellent papers that have been submitted on one or another of the above topics, but that could not be included in the regular sessions owing to the limitations on time. R. F. Muraca will wield the gavel in these proceedings.

An outline of the technical sessions, reception and banquet follows.

—Martin Goldsmith

Wednesday, April 26

9:00 a.m.	Mezzanine Ballroom
DETONATION PHENOMENA	
9:00 a.m.	Lobby Ballroom
RADIATION FROM ROCKET EXHAUSTS (Secret)	
2:00 p.m.	Mezzanine Ballroom
DETONABILITY OF PROPELLANTS	
2:00 p.m.	Lobby Ballroom
DESTRUCTIVE INSTABILITY OF LIQUID ROCKETS (Confidential)	
6:30 p.m.	Mezzanine Ballroom
RECEPTION	
Sponsored by Pratt and Whitney Aircraft Div.	
7:30 p.m.	Mezzanine Ballroom
BANQUET	

Toastmaster: Charles T. Roelke, General Manager, Florida Research and Development Center, Pratt and Whitney Aircraft Div.

Speaker: Maj. Gen. Don R. Ostrander, Director, Launch Vehicle Programs, National Aeronautics and Space Administration

Thursday, April 27

9:00 a.m.	Mezzanine Ballroom
BOILING AND NEAR-CRITICAL HEAT TRANSFER	
9:00 a.m.	Lobby Ballroom
TWO PHASE FLOW IN NOZZLES	
8:00 p.m.	Mezzanine Ballroom
ADDITIONAL SUBMITTED PAPERS	
8:00 p.m.	Lobby Ballroom
LAG PROCESSES IN ROCKET NOZZLES	
Friday, April 28	
FIELD TRIP	

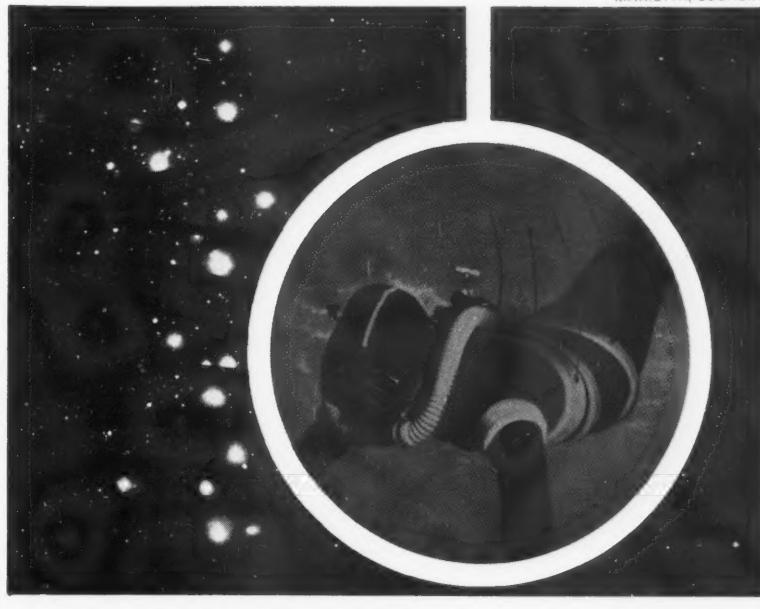
Solid-Rockets Seminar

The Delaware Section of ARS and the Univ. of Delaware, with the support of Hercules Powder Co. and Thiokol Chemical Corp., are presenting an 11-session seminar on solid-propellant rocketry for undergraduates of the University to acquaint them with this fast-growing and challenging field. Bruce C. Lutz, associate professor of electrical engineering at the University, is the moderator.

WET SPACEMAN ■ The Null-Gravity Simulator—developed by Lockheed/Georgia—rotates submerged spacemen up to 80 r.p.m. to create the effects of weightlessness. This device in the Human Factors Laboratory is just one of the diverse aerospace research and manufacturing capabilities at the Georgia Division.

LOCKHEED/GEORGIA

MARIETTA, GEORGIA



Joint ARS-Oak Ridge Space-Nuclear Conference Scheduled for May 3-5

The many problems of nuclear-powered spacecraft design will be explored in a joint AMERICAN ROCKET SOCIETY and Oak Ridge National Laboratory meeting to be held in Gatlinburg, Tenn., on May 3-5.

The program was jointly organized by John S. Luce, formerly of Oak Ridge, and C. J. Wang of the ARS Nuclear Propulsion Committee. Leading researchers in nuclear-propulsion problem areas will present papers on such key issues as advanced nuclear propulsion, nuclear systems and components research, nuclear electric propulsion, nuclear-vehicle performance, and radiation effects and hazards.

One of the closed sessions will be devoted to the progress made in major nuclear-propulsion projects, such as Rover, Pluto, Orion, Snap, and Spur.

Recent advances in controlled-fusion research, including papers on British and European progress in this field, will be the subject of another session.

The technical program will be presented in concurrent sessions covering a total of nine subject areas. A field

trip to the Oak Ridge National Laboratory has been scheduled, and bus transportation will be made available for those who wish to attend.

Two of the sessions—Nuclear-Vehicle Performance and Progress on Nuclear Propulsion and Power Programs—are classified Secret (Restricted Data).

Three luncheons are scheduled. On Wednesday, May 3, Harold B. Finger, chief of the AEC-NASA Nuclear Propulsion Office, will be the speaker. Thursday's speaker will be Brig. Gen. Austin W. Betts, director of military applications for the AEC, and Friday the luncheon speaker will be Allen F. Donovan, senior vice-president of Aerospace Corp.

Alvin M. Weinberg, director of Oak Ridge National Laboratory, will deliver a key address on "The Impact of Large-Scale Research in the USA" at the banquet to be held on Thursday evening, May 4th. Program follows:

Wednesday, May 3

Morning

OPENING SESSION

On the calendar

1961

- April 4-6** ARS Conference on Lifting Re-entry Vehicles: Structures, Materials, and Design, Riviera Hotel, Palm Springs, Calif.
- April 4-6** Symposium on Electromagnetics and Fluid Dynamics of Gaseous Plasma, co-sponsored by Polytechnic Institute of Brooklyn, IRE, IAS, and U.S. Defense Research Agencies, Engineering Societies Building, New York, N.Y.
- April 12-13** Symposium on Information and Decision Processes, Purdue Univ., Lafayette, Ind.
- April 18-20** Symposium on Chemical Reaction in Lower and Upper Atmospheres, sponsored by Stanford Research Institute, Mark Hopkins Hotel, San Francisco.
- April 24-27** 32nd Annual Aerospace Medical Association Conference, Chicago, Ill.
- April 26-27** AIME High Temperature Materials Conference, Pick-Carter Hotel, Cleveland, Ohio.
- April 26-28** ARS Propellants, Combustion, and Liquid Rockets Conference, Palm Beach Biltmore, Palm Beach, Fla.
- April 30-May 4** 7th ISA National Aero-Space Instrumentation Symposium, Adolphus Hotel, Dallas, Tex.
- May 3-5** ARS/ORNL Space-Nuclear Conference, Oak Ridge National Lab, Gatlinburg, Tenn.
- May 8-10** IRE National Aerospace Electronics Conference, Biltmore & Miami Hotels, Dayton, Ohio.
- May 9-11** Western Joint Computer Conference, Ambassador Hotel, Los Angeles, Calif.
- May 22-24** ARS National Telemetering Conference, Sheraton Towers Hotel, Chicago, Ill.
- May 22-24** National Symposium on Global Communications, co-sponsored by AIEE and IRE, Hotel Sherman, Chicago, Ill.
- June 13-16** National IAS-ARS Joint Meeting, Ambassador Hotel, Los Angeles.
- June 19-21** Heat Transfer and Fluid Mechanics Institute Conference, Univ. of Southern California, Los Angeles.
- June 19-21** International Academy of Astronautics on Earth Satellites and Re-entry Trajectories, Paris.
- June 23-24** Franco-Italian Colloquium on Sounding Rockets, Paris.
- June 26-28** First European Symposium on Space Technology, London.
- July 9-14** 4th International Conference on Bio-Medical Electronics and 14th Conference on Electronic Techniques in Medicine and Biology, Waldorf-Astoria Hotel, New York, N.Y.
- Aug. 7-9** ARS Guidance and Control Conference, Stanford Univ., Palo Alto, Calif.
- Aug. 16-18** ARS International Hypersonics Conference, MIT, Cambridge, Mass.
- Aug. 23-25** ARS Biennial Gas Dynamics Symposium, Northwestern Univ., Evanston, Ill.
- Aug. 28-Sept. 1** International Symposium on Rockets and Astronautics sponsored by Japanese Rocket Society, Tokyo.
- Aug. 28-Sept. 1** International Heat Transfer Conference, Univ. of Colorado, Boulder, Colo.
- Oct. 2-7** XIth International Astronautical Congress, Washington, D.C.
- Oct. 4-6** American Society of Photogrammetry Semi-Annual Convention, Biltmore Hotel, New York, N.Y.
- Oct. 9-15** ARS SPACE FLIGHT REPORT TO THE NATION, New York Coliseum, New York, N.Y.

LUNCHEON

Toastmaster: H. G. MacPherson, Oak Ridge National Laboratory.

Speaker: H. B. Finger, chief of AEC-NASA Nuclear Propulsion Office, "The Role of Fission Reactors in Space."

Afternoon

ADVANCED CONCEPTS FOR NUCLEAR PROPULSION AND POWER NUCLEAR SYSTEMS AND COMPONENTS RESEARCH

Evening

Speaker: Wernher von Braun

Thursday, May 4

Morning

PROGRESS ON NUCLEAR PROPULSION AND POWER PROGRAMS (Secret) NUCLEAR-ELECTRIC PROPULSION

LUNCHEON

Afternoon

NUCLEAR VEHICLE PERFORMANCE (Secret)

RADIATION EFFECTS AND HAZARDS

BANQUET

Toastmaster: Harold W. Ritchey, President of the American Rocket Society

Speaker: Alvin M. Weinberg, Director of Oak Ridge National Laboratory, "The Impact of Large-Scale Rocket Research in the USA."

Friday, May 5

Morning

PROGRESS OF CONTROLLED FUSION RESEARCH

LUNCHEON

Speaker: Allen F. Donovan, Senior Vice President of Aerospace Corp.

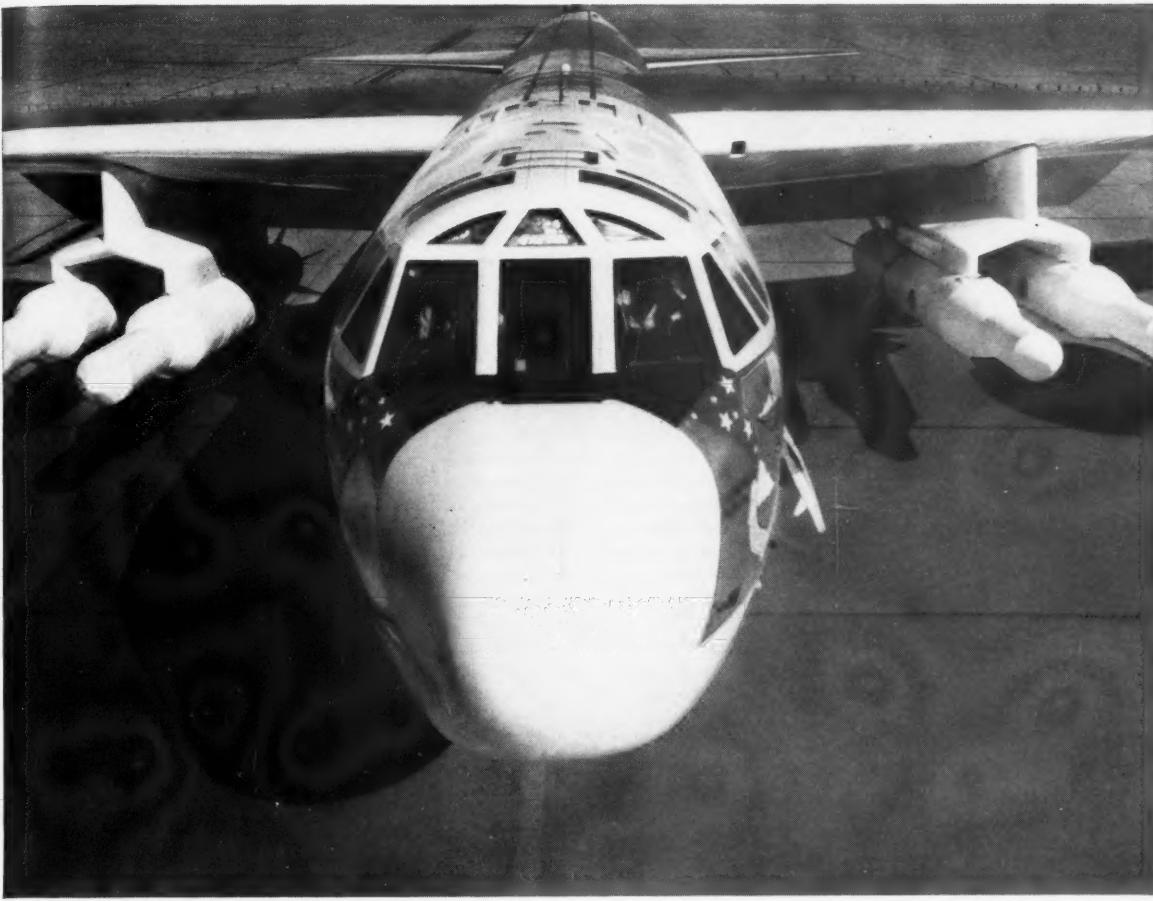
Afternoon

CLOSING SESSION

A Token of Appreciation

At a recent annual meeting, the ARS Arrowhead Section presented its first president, John B. Gustavson, at the right, a handsome desk set in appreciation of his efforts in founding the Section in 1960. The Section's new president, Larry Thackwell, senior vice-president of Grand Central Rocket Co., makes the presentation. Looking on is the guest speaker of the evening, Homer Joe Stewart, NASA's first director of program planning, now returned to CalTech as professor of aeronautics and special assistant to the director of JPL. Dr. Stewart discussed long-range planning of NASA programs.

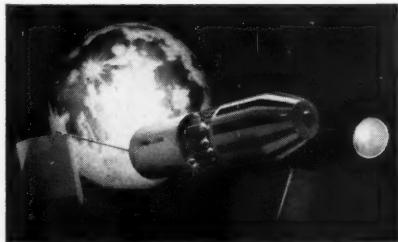




MISSILE BOMBER. New "H" model is latest version of famous Boeing B-52 missile bomber, most versatile long-range weapon system in U.S. Air Force arsenal. B-52H here carries mock-ups of four Skybolt air-launch ballistic missiles. B-52s can also carry

supersonic Hound Dog missiles for in-flight launching toward distant targets. Flying high or low, B-52s will provide an almost undetectable launch pad for missiles. They can also carry regular load of gravity bombs, and strike up to five targets on single mission.

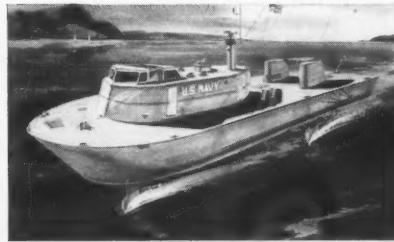
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RESEARCH STATION. Model of space research station designed by Boeing to accommodate 12 men and remain in earth orbit, serving as research station or interplanetary launch site.



SPACE CHAMBER. Boeing multi-stress chamber simulates six conditions of space travel in research to develop protective environments required for space vehicle crews. Chamber will also be used to test conditions in moon stations.



"FLYING" BOAT. Drawing of 115-foot hydrofoil craft Boeing is building for U.S. Navy. Riding out of water, hydrofoil will "fly" on underwater wings at speeds up to 45 knots. Powered by two 3000-hp gas turbine engines, craft will be the biggest hydrofoil ever built.

BOEING

IAF to Hold XIIth International Congress on October 2-7 in Washington

The AMERICAN ROCKET SOCIETY will act as host for the XIIth International Astronautical Congress to be held in Washington, October 2-7.

The program being organized by Samuel Herrick of UCLA, member of the ARS Board of Directors, will include two types of sessions—the standard technical sessions with formal papers and roundtable discussions.

These sessions will cover astrodynamics and guidance, communications and instrumentation, propulsion, vehicle design and testing, space exploration, human factors and biological environment, and space law.

Those who wish to submit papers in any of these areas should mail complete abstracts by May 1 to Chairman, XIIth International Astronautical Congress, AMERICAN ROCKET SOCIETY, 500 5th Ave., N.Y. 36, N.Y.

The abstract requirements for the Congress will be different than the ones generally required for an ARS meeting. Abstracts must contain all

important detailed information including results and graphs or other figures necessary for substantiation of the report, so that a reviewer can make a careful scientific judgment of its worth. The abstract should be limited to four pages in length, including figures. Two pages of written material and two pages of figures are suggested.

The abstracts of all accepted papers will be bound into a booklet, which will serve as the official meeting document. Full papers will be required by September 15th. These papers will be reviewed for publication in the official Congress "proceedings" volume to be prepared after the meeting.

The International Astronautical Federation is composed of 37 professional societies from 30 countries who are joined to promote and stimulate the achievement of space flight as a peaceful project. The IAF was founded in 1950. Since that time, annual Congresses have been held to disseminate technical and other information on space flight.

TENTATIVE SCHEDULE OF EVENTS

Monday, October 2

Morning—Academy of Astronautics Meeting
IAF Plenary Session

Afternoon—IAF Plenary Session

Evening—IAF Opening Ceremony
Informal Reception

Tuesday, October 3

Morning—Astrodynamics Roundtable
Space Propulsion Session

Afternoon—Structures Roundtable
Energy Conversion Session

Evening—Formal Reception

Wednesday, October 4

Morning—Space Physics Roundtable
Combustion Session
Institute of Space Law

Afternoon—Space Medicine Roundtable
Guidance Session
Institute of Space Law

Evening—Special Evening Program

Thursday, October 5

Boat Tour to Mt. Vernon

Friday, October 6

Morning—Space Communications Roundtable
Vehicles Session

Afternoon—Instrumentation Roundtable
Bioastronautics Session

Evening—Banquet

Saturday, October 7

Open for sightseeing and possible trips to plants in the Washington area.

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Tentative Program Set For NTC on May 22-24

A tentative program has been set for the 1961 National Telemetering Conference which will be held at the Sheraton Towers Hotel in Chicago on May 22-24.

This year's conference will have the theme of "Science and Education in Telemetry," and is sponsored by the ARS, AIEE, IAS, ISA, and the IRE.

The program, headed by Robert G. Brown of AC Spark Plug Div. of General Motors, will have 15 technical sessions devoted to industrial, commercial, and space telemetry. Three workshop sessions will discuss Telemetry Standards, Telemetry in Europe, and Telemetry Education.

In addition to the workshop sessions, there will be sessions on Industrial Telemetry, Transducers, Advanced System Techniques, Data Processing and Presentation, Signal Conditioning, Flight Test Data Systems, PCM Systems, Underwater Measurements, Bio-Medical Telemetering, and RF Components and Techniques.

Further details on the technical program will be included in the printed program to be sent out in the latter part of April.

ENTS
eting



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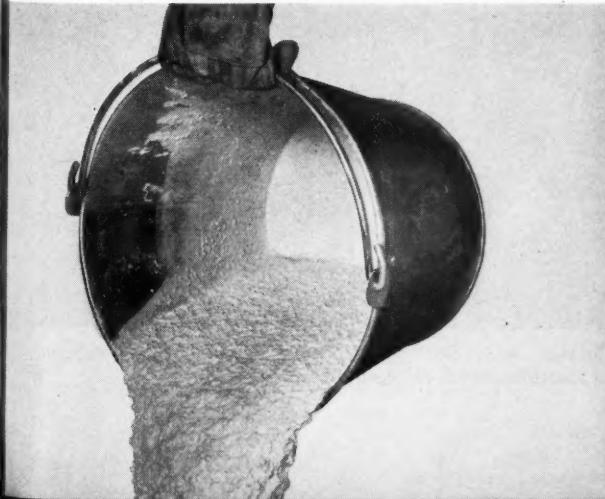
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ARS President Harold W. Ritchey of Thiokol has a word with Maj. Gen. Kenneth B. Hobson, commander, OOAMA, at the banquet.



Luncheon speaker Kurt Stehling of NASA listens attentively to remarks by John P. McGovern of Thiokol, ARS Utah Section President.



Peter L. Nichols of SRI takes a bow as Richard D. Geckler of Aerojet looks on in background.



Gen. Samuel Anderson, commander of AMC, banquet speaker.

Solid Rocket Conference Draws Attendance of 650

The second annual ARS Solid Propellant Rocket Conference, held in Salt Lake City Feb. 1-3, was up with the times. The papers, with few exceptions, reflected the interest in high-performance rockets for space and ballistic-missile applications that dominates the industry today. Seventeen of the 20 papers scheduled in the four sessions dealt with some aspect of bettering the rocket mass ratio.

The classified session on Minuteman propulsion was exceptionally popular. Interest in this special session was sharpened by the successful flight of the first Minuteman vehicle at the same time as the conference and the exhibit of the "county-fair" mockup by the Air Force. It is hoped that the papers can be published and made available to those with security clearance and need-to-know.

The first session dealt with structural problems. Max Williams of Cal-Tech, the session chairman, brought out the increased complexity of stress analysis with increased rocket size. Wei of Curtiss-Wright and Zak and Ballard of Purdue Univ. presented papers on analysis of metal rocket chambers. Both emphasized the necessity of considering more than the internal pressure load and discussed skirt joints, flight loads, and thermal stresses. Lianis of Purdue analyzed the deformation during horizontal storage of a visco-elastic propellant bonded to a rigid cylindrical case, while Weleff of Grand Central Rocket described an assembly technique for potting a spherical propellant charge to widen its temperature conditioning range. The paper by Hunter, Foster, and Mongum of Thiokol discussed some general aspects of propellant binder crystallization.

In the session on manufacturing methods, with Dean Hanink of GM's Allison Div. as chairman, Feola of Curtiss-Wright stated that 200,000 psi yield strength materials have been sufficiently developed and tested to be

considered "state of the art" and discussed fabrication of 31- to 65-in. steel cases. The chambers, fabricated for both Minuteman and Pershing, ranged from conventional ASI 4130 sheet material alloys to high-performance flight weight cases utilizing vacuum melted D6AC and Tricent steel at 200,000 psi yield strength. Cylindrical sections fabricated from rolled and longitudinally welded sheet metal have been replaced by ring forgings and more recently by roll-formed cylinders. Dome forgings have replaced weldments to permit the machining of integral bosses and thrust skirts. Heat transfer of large diameter, thin-walled case is presently going through transit from "art" to "science," the author noted.

In the same session, Crimmons of Aerojet presented metallurgical aspects of shear spinning ultra-high-strength steels, while Podell and Kotfila of the same company discussed design and fabrication of titanium rocket chambers. Hayes and Watanabe of Kelsey-Hayes Co. discussed the general aspects of movable nozzles, contending that in the present state of the art of thrust vector control movable nozzles replace previous methods. The materials used in movable nozzles are graphite and leached fiber glass and reinforced phenolic plastic. New manufacturing techniques are being proposed to produce structures that were heretofore unavailable, and these advances should make possible great improvement in reliability and efficiency of movable nozzles.

The interest in very large rockets was noted by Voris of Thiokol in discussing segmented vs. on-site loaded rockets. The author drew the conclusion that on-site loaded solid-propellant rocket engines provide more growth potential than segmented engines. With proper emphasis in future development programs on manufacturing facilities and propellants, extremely large on-site loaded engines



Rear Adm. Charles Martell, Navy R&D chief, makes a point during luncheon talk as Loren Morey of Hercules Powder looks on.

will be quite feasible, he stated.

In the session on materials, Kitchin of Curtiss-Wright spoke of the properties of 20-25% nickel steels as a new series of ferrous alloys which appear promising for application to solid-propellant rocket cases. The surge of interest in plastic materials for insulation and structural use in solid-propellant rockets was noted by the chairman, George R. Irwin of NRL, in commenting on papers of Sterry, Page, McKague, and Rosato. Continuous filament and fabric materials have been used extensively to form structural members of rocket motor components. Glass rovings filled with epoxy resins have very high strength-to-weight ratios. Helically wound structures of these materials have been used for several years. This method of fabrication is well adapted to the construction of rocket cases.

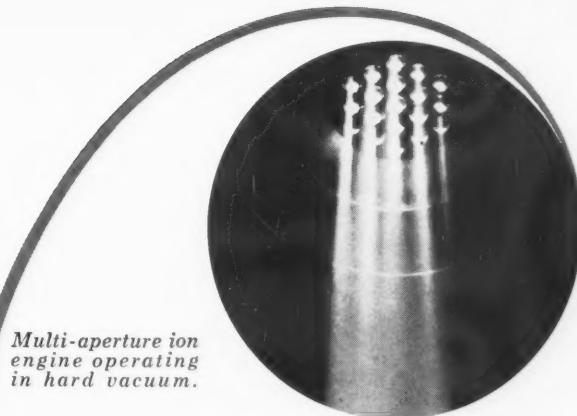
Some aspects of internal ballistics were covered by Stone of Rohm & Haas, Rogers of Thiokol, and Segal of Aerojet in the first three papers of the session on rocket and grain design problems. Armstrong of JPL spoke on staging solid-propellant rockets for spacecraft retardation, and Baxter of STL discussed a consumable case rocket motor in a paper unique for being the result of "homework" rather than being produced under the sponsorship of contract. The consumable case rocket was recommended as a first stage for medium-sized ICBM usage and as a second stage for much larger missiles. The consumable rocket does not have a case in any conventional sense, the propellant charge instead being surrounded by an ablative material consumed during rocket operation.

The meeting, which drew an attendance of more than 650, was co-sponsored by the ARS Propellants and Combustion and Solid Propellant Rockets Committees. Joseph H. McKenna of Thiokol was general chairman of the meeting, while John P. McGovern of Thiokol, President of the ARS Utah Section, was deputy general chairman. Richard D. Geckler of Aerojet was general program chairman, while Loren E. Morey of Hercules Powder was solid rocket program chairman and Peter L. Nichols of Stanford Research Institute was propellants and combustion program chairman.

—Loren E. Morey

ARS Sacramento Section Sponsors Educational Council

The ARS Sacramento Section has been instrumental in starting an Inter-Society Educational Council in the



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Central California area to increase interest there in science education. The following organizations make up the Charter Membership of the Council: Sacramento Junior Museum, American Society of Metals, Institute of Traffic Engineers, Structural Engineering Assn. of Central California, American Society of Tool and Manufacturing Engineers, ASME, Gravity Assn. for Universal Scientific Studies, IAS, American Institute of Industrial Engineers, Society of Technical Writers and Publishers, Sacramento Valley Astronomical Society, Rocket Research Institute Inc., ARS, California Society of Professional Engineers, and (pending) ACS, Sacramento Geological Society, and the Chemical Engineers Club of Sacramento. ARS member Al Apodaca is temporary chairman of the Council (home address: 4536 Surita St., Sacramento, Calif.).

Arrowhead Section Co-sponsors Missile Courses

The Norton AFB's Employee Career and Development Branch and the newly organized ARS Arrowhead Section of San Bernardino and Riverside counties in Calif. have conducted a series of courses in basic missile technology for personnel of the Directorate, Supply and Transportation, Norton AFB.

The curriculum of one course consisted of the following subjects: History of missiles, types and tactical uses, introduction to USAF missiles, and missile systems and subsystems.

A survey course on USSR missiles was also presented, covering historical development of the Soviet missile and

propulsion program; past, present, and future types and tactical uses of Soviet missiles; description and performance evaluation of the Soviet space program; and USSR launch-site locations, etc.

Instructor of both courses was Lou Crider of Norton AFB, who was vice-president of the Arrowhead Section last year.

SECTION NEWS

Antelope Valley: An overflow crowd of members and wives attended a dinner meeting in January to hear Chan Hamlin of North American Aviation speak on "Launching Super Spaceships." His talk covered the problems of handling, transporting, and launching future space systems. Slides and a motion picture were used to illustrate various possibilities for overcoming problems associated with very large vehicles required for a successful venture into space by man. An added highlight to the meeting was the awarding of an Atlas model as a door prize.

—Leslie O. Harrington

Central Colorado: The January meeting was held on the campus of Colorado Univ. in combination with a winter seminar prepared by our local ARS Education Committee under the chairmanship of T. Bradley. Approximately 450 people attended. The meeting started with four panel discussions, held from 3:00 to 5:30 p.m., on the following topics:

Propellants & Propulsion Systems Moderator, E. Ring

Vehicle Configurations Moderator, J. Burridge
Guidance and Control Moderator, R. Crandell
Performance & Flight Mechanics Moderator, L. Soderberg

The evening session, held at the University Memorial Center between 7:00 and 10:00 p.m., featured guest speaker George P. Sutton, manager of advanced design for Rocketdyne. His topic was "Future Propulsion Systems for Interplanetary Flight." In conclusion to his comprehensive review of propulsion state of the art and future potentials, Sutton pointed out that space technology is changing so rapidly that only by continuing study can engineers and scientists hope to keep abreast of the latest knowledge in their fields or specialties. Industry today needs, he said, the superior technical individual and not the "organization man." The former people are the ones that he feels will be making the necessary contributions to advance the state of the art.

Al Africano, twice past president of ARS, was a panelist as well as an attendee at this meeting.

—Jonathan E. Boretz

Columbus: Sixty members and guests attending the February meeting at Battelle Memorial Institute saw two movies, "The Nautilus" and "The Geiger Tigers," and heard guest speaker Russell Edwards of GE Flight Propulsion Laboratory at Evendale, Ohio, describe electrical-propulsion systems, ion propulsion in particular. Edwards stated that GE developed the first ion engine in the U.S. in 1958. Uses and advantages of ion propulsion and its application to space vehicles were discussed. Slides highlighted his

1961 ARS Meeting Schedule

Date	Meeting	Location	Abstract Deadline
April 4-6	Lifting Re-entry Vehicles: Structures, Materials, and Design Conference	Palm Springs, Calif.	Past
April 26-28	Propellants, Combustion, and Liquid Rockets Conference	Palm Beach, Fla.	Past
May 3-5	Space-Nuclear Conference	Gatlinburg, Tenn.	Past
May 22-24	National Telemetry Conference	Chicago, Ill.	Past
June 13-16	National IAS-ARS Joint Meeting	Los Angeles, Calif.	Past
Aug. 7-9	Guidance and Control Conference	Palo Alto, Calif.	Past
Aug. 16-18	International Hypersonics Conference	Cambridge, Mass.	Past
Aug. 23-25	Biennial Gas Dynamics Symposium	Evanston, Ill.	Past
Oct. 2-7	XIIth International Astronautical Congress	Washington, D.C.	May 1
Oct. 9-15	ARS SPACE FLIGHT REPORT TO THE NATION	New York, N.Y.	April 15

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presentation, and an active question and answer period followed.

—James A. Laughrey

Connecticut Valley: A joint dinner meeting of the local ARS and IAS sections was held in February at the Bradley Airport Terrace Room, and an excellent turnout of members voted for more joint meetings in the future. The principal speaker of the evening, Milton B. Trageser, assistant director of the MIT Instrumentation Laboratory, was introduced by H. E. Francis, president of the ARS Connecticut Valley Section and vice-president of the local IAS section.

Trageser spoke on a topic obviously near and dear to his heart, "A Recoverable Interplanetary Space Probe." He described how a 342-lb instrumented probe would make a 3-yr round trip to Mars, for example, take a single photograph at a height of about 5000 mi and return to a 1-mi target area on earth. His nine years of experience in the field of self-contained guidance and control systems, together with his work on this project for the past two years, stood him in good stead during a lively question and answer period.

—C. F. Turner

Kansas City: In January, the Section met jointly with the local section of the IAS, 42 members of the two societies enjoying a social hour and chicken dinner at the Wishbone Restaurant and approximately 30 additional members joining them in the post-dinner program to hear R. A. Fitzgerald of McDonnell Aircraft present an excellent illustrated talk on Project Mercury.

National Capital: The Section began its operations for 1961 with a new

The Data Goes Round and Down



"Project Mercury Computing and Data Flow" was the subject of a recent talk to the new ARS Atlanta Section by James H. Turnock Jr., project manager of IBM's Project Mercury work, which includes programming and operation of real-time trajectory computations and telemetry analysis. Shown chatting with Dr. Turnock (center) after his talk are, from left, Atlanta's program chairman J. W. Tatom; secretary A. P. Pennock; president R. B. Ormsby Jr.; and publicity chairman H. A. Curth.

slate of officers comprised of Andrew G. Haley, president; Hunter C. Harrison, vice-president; Richard A. Carpenter, treasurer; and J. Gordon Vaeth, secretary. The January meeting featured as guest speaker Robert L. Krieger, director of NASA's Wallops Island Station, who described this installation and its mission. He related its progress since its inception, and pointed out a number of other systems that have developed as a result of NASA's original efforts at Wallops. The importance of Wallops to the national space program was clearly evident from his description of its functions.

An attendance of more than 500 marked the Section's panel discussion of "The Outlook for Manned Space Vehicles," held on the evening of Feb. 21 at the Interdepartmental Auditorium of the Labor Dept. building. The panel, introduced by Section President Andrew G. Haley, was moderated by Theodore von Karman, director of AGARD, and included Rear Adm. Thomas F. Connally, Bureau of Naval Weapons; Alfred Mayo of NASA's Office of Life Science Programs, AAS president; Harold W. Ritchey of Thiokol, ARS president; H. Guyford Stever of MIT, IAS president; and Eugen Sanger, director of the Stuttgart Re-

An Outlook for Manned Space Vehicles



Theodore von Karman, director of AGARD, presides over a distinguished panel discussing the outlook for manned space vehicles at a recent meeting of the ARS National Capital Section. Introduced by Andrew G. Haley, National Capital president, at the far left, the panel members are, left to right, H. Guyford Stever, IAS president; Alfred Mayo, AAS president; Dr. von Karman; Eugen Sanger, director of the Stuttgart Research Institute for Rocket Propulsion Physics; Rear Adm. Thomas F. Connally, USN, asst. chief of the Navy Bureau of Weapons for astronautics and Pacific Missile Range operations; Harold W. Ritchey, ARS president; and H. C. Harrison, National Capital vice-president.

search Institute for Rocket Propulsion Physics and president of the German Rocket Society. Each of the panel members presented a short paper on the subject, and these presentations were followed by discussion and questions from the audience.

—J. Gordon Vaeth

New England: The Section held its first 1961 meeting in January at the Arthur D. Little Center, Acorn Park, Cambridge, Mass. Some 100 members and guests heard featured speakers Donald S. Allan, group leader, and Winslow A. Sawyer, project manager, both with A. D. Little, discuss "Hazards of Liquid Hydrogen—The Workhorse Fluid of Space," a report on investigations to establish safety criteria for storage and handling, quantity-distance relationships, vapor-cloud dissipation, thermal-radiation hazards, and explosive yields. A film showing tests, including spill and ignition of 5000-gal quantities of liquid hydrogen at Otis AFB, complemented their discussion.

—L. R. Michel

Northern California: The regular February meeting, attended by 75 persons, 12 of which were from the Navy Postgraduate School, Monterey, Calif., heard guest speaker Y. C. Lee, president of the new Douglas subsidiary Astro Power, Inc., discuss "Propulsion Systems—Present and Future." Lee described the current "performance kick" of the rocket industry and presented a convincing argument for added emphasis on cost reduction and improved reliability. He recognized that a tradeoff of performance may be necessary to realize the cost and reliability objectives, but speculated that notwithstanding this the next decade will see specific impulses of 500 sec at operating pressures up to 4000 psi with single engines capable of 4-5 million pounds of thrust.

During the question period following his opening remarks, Lee explained the anticipated roll of Astro Power, Inc. Its ambitious task, he said, includes development of throttleable, high-energy liquid-propellant engines and research of advanced nuclear and electrical-propulsion concepts.

—Robert O. Webster

North Texas: The Section held its annual meeting in Fort Worth in January. Guest speaker Edward Goldberg, manager of space-vehicle systems for RCA, presented a discussion of the Tiros II satellite meteorological system. Movies of the Tiros program were shown and photographs of the earth's cloud cover obtained from Tiros I were presented. Mr. Goldberg answered questions on some of the de-



Christiaan Huygens
1629-1695

The Dutchman who could WALK THROUGH WALLS

For Christiaan Huygens the barrier between "pure" and "applied" research was as insubstantial as a rainbow. He made an intensive study of the theory of probabilities. He invented the pendulum clock. He perfected the telescopic lens. He made monumental contributions to geometrical optics and to "pure" light-wave theory.

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tails of the program.

At this meeting the 1961 officers were presented and Ronald E. Krape assumed the duties of Section President.

Greater Philadelphia: In January, Naval Air Material Center's Air Crew Equipment Lab in Philadelphia was host to the Greater Philadelphia Section, which was newly formed by merging the old ARS Philadelphia and Valley Forge Sections. Newly elected officers of Greater Philadelphia are Logan B. Cowles, president; Charles Stokes, vice-president; Bernard Cohen, secretary; and Robert Kirby, treasurer.

Approximately 120 members attended a dinner before the meeting at ACEL. During dinner, Capt. Roland A. Bosee, USN, director of ACEL, and Edwin Hender, superintendent of its Life Sciences Research Div., described the mission of ACEL and its technical relationships with other laboratories as well as ones at NADC, Johnsville.

Then, later, at an Environmental Stress Branch demonstration, members were shown how temperature measurements are made on a heat-stressed subject in an exposure suit and flight garments. Edmund Gifford of the Human Engineering Branch, an ARS member, showed how anthropometric measurements are made of reach measurements of a subject wearing a Navy full-pressure suit in the ACEL flexible cockpit. He also explained the use of various vision-study apparatus, including spectrophotometers and tachistoscopes.

As an added attraction, Cmdr. Robert L. Burdick, USN-MC, deputy director of ACEL, presented a movie on the stress effects of oxygen deprivation as measured in experimental subjects in ACEL altitude-chamber tests. Dr. Burdick also described electronic apparatus designed to measure stress effects on pilot motor-performance and judgment.

—Arnold Koch

Princeton: The February meeting was opened by Section President Sidney Sternberg introducing guest speaker for the evening, James D. Hardy, director of research at the Navy's Aviation Medicine Acceleration Laboratory in Johnsville, Pa.

After describing some of the problems and objectives in making man's journey through space as safe as possible, Dr. Hardy emphasized the difficulties faced by man in a weightless state and when exposed to high G at the extraordinary high speeds of spacecraft. He described development of G suits, advances to the present contour couch for the astronaut, and protection by water immersion. Also, flight simulation and extensive

One Reason Why It's All Worthwhile



Harvey Cook, left, president of the ARS Tennessee Section, discusses the formation of an ARS student chapter with, to his left, Wolfhart Goethert, William Cathey and Mickey McCrary, engineering students at the Univ. of Tennessee.

tests in the Navy centrifuge were shown in a special film.

The meeting was reluctantly adjourned after the speaker was rescued from the many questions his discussion stimulated in the audience of approximately 85.

—H. M. Gurin

Tennessee: Guest speaker at the January meeting was Mark Ghai, manager of the Electrical Space Propulsion Section of the GE Flight Propulsion Laboratory. Dr. Ghai discussed electrical-propulsion methods which might be used for various space missions, such as orbit transfers and lunar and Martian orbits. Some of the propulsion methods discussed were the electrothermal (arc-jet) rocket, the electrostatic (ion) rocket, and the electro-

magnetic (MHD or plasma-jet) rocket.

The February meeting was held on the evening following the first successful Atlas-Mercury test launch, and a very interesting and apropos presentation on "The Design Operation of the Mercury Capsule" was presented by Frank Morgan, McDonnell Aircraft's representative for all NASA projects. He began by discussing some data from the previous day's flight and from the successful flight of "Ham, the Astro-Chimp," then outlined the basic requirements and objectives of the Mercury program, and described associated tests and engineering problems encountered and methods of solution. His presentation was concluded by a short movie about the Mercury program, followed by a question and answer session.

The Education Committee of the Tennessee Section has started a series of weekly lectures on space sciences for local high school students. The series was arranged to introduce interested students to the wide variety of professional careers in the space field. The initial topics and speakers are: "Space Travel and Trajectories," Robert Dietz; "The IGY and Satellites," Art Hinners; "Human Survival in Space," Phil Rubins; "Space Propulsion—Nuclear and Other," Andy Lennert; and "Space Guidance and Navigation," Ralph Billings.

—Thomas J. Gillard

Utah: In January, the Section held an installation dinner at the Hotel Utah in Salt Lake City which was attended by 100 members and guests, including these guests of honor: George D. Clyde, governor of the State of Utah; Ray Olpin, president of the Univ. of Utah; John Higginson,

Success for the Future



New president of the ARS Utah Section, John P. McGovern, with the bow tie, accepts good wishes for his term in office from his predecessor, Joseph H. McKenna, while Utah's Governor, George D. Clyde, and Bishop Joseph L. Federal of the Salt Lake City Diocese look on approvingly during a recent installation meeting of the Section.

general manager of Thiokol's Utah Div.; **Edward Nauman**, general manager of Thiokol's Wasatch Div.; **John Greer**, general manager of Hercules Powder Co.; and **Donald Tasker**, general manager of the Marquardt Corp.

Guest speaker of the evening was **Edward Flesh**, engineering manager of Project Mercury at McDonnell Aircraft Corp. His discussion included a history of the "man in space" program, the philosophy behind putting a man in space, and the technology of the Mercury space capsule. He used slides showing the trajectory to be followed by the first Mercury capsule flights and also explained the metallurgical breakthroughs that were required in the construction of the lightweight capsule.

The guest speaker for a meeting held late in February was **John N. Sherman**, Space Programs Superintendent, Chemical Propulsion Div., Hercules Powder Co. His topic was "Space Applications of Solid-Propellant Rockets." The advantages of solid-propellant rockets—reliability, simplicity, low cost, reproducibility, high performance, and flexibility—were discussed. Sherman went into the history of the Scout program, a brief discussion of the four stages—Algol, Castor, Altair, and Antares—and how this particular rocket demonstrated the advantages of solid-propellant rockets. The use of a Scout rocket to place a 12-ft Mylar balloon in orbit Feb. 17 was a milestone for solid-propellant rockets, he believes. An NASA movie on the Scout Program and system concluded his evening's presentation.

Wichita: The initial 1961 dinner meeting was held in the Boeing Airplane Co. cafeteria jointly with the local IRE section. Approximately 170 ARS and IRE members and guests were present to hear guest speaker **Sol Matt**, manager of systems engineering for GE's Light Military Electronics Div., discuss during a classified session missile guidance.

—C. M. Long

STUDENT CHAPTER

Univ. of Washington: At the regular January meeting, the Chapter heard guest **Francis Reynolds** of Boeing discuss Dynasoar. Among the many interesting features described was the instrument panel: It was explained how temperatures are determined and presented to the pilot and how he is kept informed of his location. Reynolds' talk was especially interesting, and many stayed after the meeting to discuss Dynasoar further.

A joint meeting with the local IAS chapter was held later in January. Our speaker was **Allen J. McMahon**



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of Space Technology Laboratories, who spoke on "Past Accomplishments and Future Plans for Space Exploration." McMahon emphasized satellite projects having the chance of becoming self-supporting and profitable. These he grouped into three main classifications: Communication, transit (for navigation), and weather satellites. He also discussed the information obtained from Explorer VI and Pioneer V and outlined plans for future satellite research.

At a regular meeting in February Joseph Marcella of Boeing spoke on "Ground Support for Minuteman." Marcella first discussed how the development of such a vast system is organized in such a way that development can proceed in a logical fashion. Then he went into as much detail as permitted on the construction of the launch-control facility, the launch facility, and means of transporting the missile.

—Patricia L. Blake

TECHNICAL COMMITTEES

Hypersonic air-breathing propulsion has been enjoying a strong upsurge of interest, and the **ARS Ramjet Committee**, chaired this year by W. H. Avery of the Applied Physics Laboratory, John Hopkins Univ., is looking forward to the opportunity to establish and encourage widespread appreciation of the potentialities of ramjets for high-speed flight.

The work of the ARS Ramjets Committee for 1961 will include as primary objectives the organization of a classified program on orbital planes and hypersonic propulsion for the joint IAS-ARS national meeting, to be held in Los Angeles in June, and an unclassified series of papers on ramjets and a state-of-the-art report for the **SPACE FLIGHT REPORT TO THE NATION**, to be held at the Coliseum in New York, October 9-15. The Committee has also dis-

cussed the possibility of a specialists meeting on ramjets for 1962.

A *national program of energy-conversion research* will be a chief objective of study for the **ARS Power Systems Committee** during 1961, and the subject of a proposed roundtable discussion at the **SPACE FLIGHT REPORT TO THE NATION**. The Power Systems Committee does not plan formal sessions for the joint IAS-ARS national meeting, but expects to present two sessions at the SFRN on the state of the art of advanced energy-conversion systems. ♦♦

Snap Prototype Completes Operational Ground Tests

The prototype of the nuclear reactor for the Snap II, VIII, and X systems (see Dec. 1960 *Astronautics*) has successfully completed operational ground testing. Developed by NAA's Atomics International Div. for the AEC, the prototype is expected to be flight-tested in the Snap 10 system in 1962 or 1963. The Snap X system employs a thermoelectric converter, and produces 1-2 kw. The prototype reactor made a 1000-hr run at design conditions in 1960.

Precision Measurement and Calibration Handbook Out

A compilation of the more important National Bureau of Standards publications over a number of years has recently been issued under the title, *Precision Measurement and Calibration, Handbook 77*, in three volumes, available from the Supt. of Documents, GPO Washington 25, D.C.: Electricity and Electronics (845 pages, \$6.00); Heat and Mechanics (965 pages, \$6.75); and Optics, Metrology, and Radiation (1025 pages, \$7.00).

Vitro Labs Developing Missile Reliability Formulas

Under Bureau of Weapons contract, Vitro Laboratories of Silver Springs, Md., will reduce Navy guided-missile reliability prediction to standard formula. Key factors involved in developing this standard procedure include the number of parts involved, environments affecting parts, length of time the system must work, and the state of the art of equipment. Reliability will be expressed as a percentage.

CHANGE-OF-ADDRESS NOTICE

In the event of a change of address, it is necessary to include both your old and new addresses, as well as your membership number and coding, when notifying ARS Headquarters in order to insure prompt service. If you are moving or have moved, send the following form to Membership Dept., American Rocket Society, 500 Fifth Ave., New York 36, N.Y.

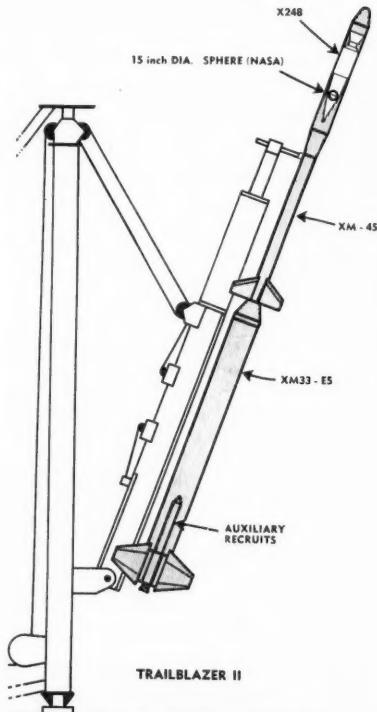
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Trailblazer II Space Probes Scheduled



Diagrammed above, the Trailblazer II space research vehicle, originated by NASA-Langley's flight physics group, and now being used by MIT's Lincoln Laboratory in the ARPA Defender reentry research program, will be developed and built in number by Atlantic Research Corp. for MIT, the first vehicle being scheduled for operation this spring. NASA-Langley will monitor the development. Two of the rocket's four stages boost up, two down, giving a spherical re-entry body a high downward velocity that is increased to 25,000 fps (orbital figure) by a small solid rocket in the sphere.

IAS-ARS Joint Meeting Set

(CONTINUED FROM PAGE 23)

line the sessions for the meeting look as follows:

Tuesday, June 13

9:00 a.m.

Electrical Propulsion I
Air Transport Logistics
Planning for Success in the One-Shot Mission
Progress Status Report on Polaris Weapons System

LUNCHEON

2:00 p.m.

Electrical Propulsion II
Advanced Transports
Instrumentation for Space
Earth Landing and Re-entry Problems

7:30 p.m.

VTOL Systems
Operations Support Equipment
Propellants and Combustion
Program Status Report on Titan ICBM

Wednesday, June 14

9:00 a.m.

Digital Computer Applications
Astrodynamics I
Space Operations and Maintenance
Orbital Aircraft

LUNCHEON

2:00 p.m.

Structures and Materials
Astrodynamics II
Space Physiology and Performance
Advanced Chemical Propulsion

7:30 p.m.

Space Law (Tentative)
Space Physics (Tentative)
Deep-Space Vehicles
Liquid Rockets

Thursday, June 15

9:00 a.m.

Communication Satellite Systems
Auxiliary Systems
Space Mission Simulation
Advanced Airbreathing Propulsion Systems

2:00 p.m.

Communications and Instrumentation
Attitude Control of Space Vehicles and Satellites
Aerodynamics
Military Applications of Space Vehicles

BANQUET AND DANCE AT THE COCONUT GROVE

Friday, June 16

Underwater Propulsion Program at NOTS

PROGRAM CHAIRMAN



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ENGINEERS

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Underwater Propulsion

(CONTINUED FROM PAGE 39)

pound of lithium is much greater at this temperature than at higher temperatures.

The bottom two graphs shown below, give the results of similar calculations for the sodium-water system. The maximum specific energy is produced at a mixture ratio of about 2, which again corresponds to combustion temperature of about 850 K. The second maximum, at a mixture ratio of 5, is a result of the heat of solution of sodium hydroxide, which is realized only when liquid water is present in the reaction products.

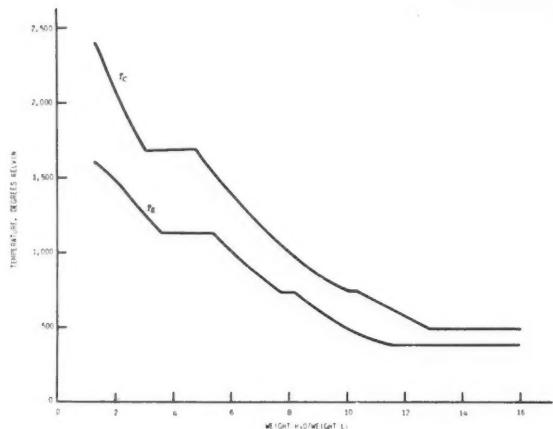
The lithium system produces five times as much energy per pound of fuel as the sodium system. Assuming

a turbine operating with 50% efficiency at a 20-to-1 pressure ratio, the lithium-water system has a specific fuel consumption of 1.5 lb per shp-hr, while the sodium system requires 7.6 lb per shp-hr. Obviously the lithium system is more efficient and would be preferred in any final application. Much of the experimental work was done with sodium, however, because of its much lower cost, lower melting point, greater reactivity, and general similarity to lithium.

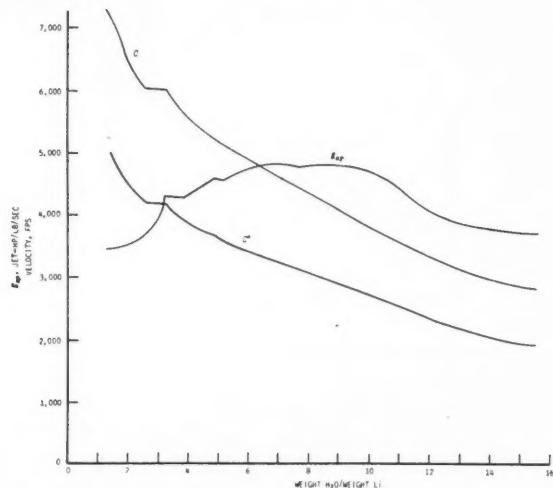
The experimental phase of the investigation was conducted in small rocket-motor test cells, such as the one shown on page 79, equipped with stands capable of measuring up to 3000-lb thrust. Most of the tests were made at about 200-lb thrust, equal to about 600 jet-HP. The sodium or lithium was melted in a stainless-steel

liner inside a steel pressure vessel. Electrical-resistance heaters were installed between the walls of the two tanks, and the fuel lines and valves were also heated to prevent the molten metals from solidifying before entering the combustion chamber. Helium was the inert gas used for pressurizing the fuel tank, because lithium, especially, reacts quite rapidly with nitrogen at elevated temperatures. Compressed air was used to pressurize the plastic-lined steel tanks which contained the synthetic sea water serving as oxidizer and diluent in these combustion tests. The water flow-rate, tank pressure, chamber pressure, and thrust were measured directly, with more-or-less standard instrumentation. The fuel flow-rate was calculated from the duration of the test and the net weight of sodium or lithium consumed. Toward

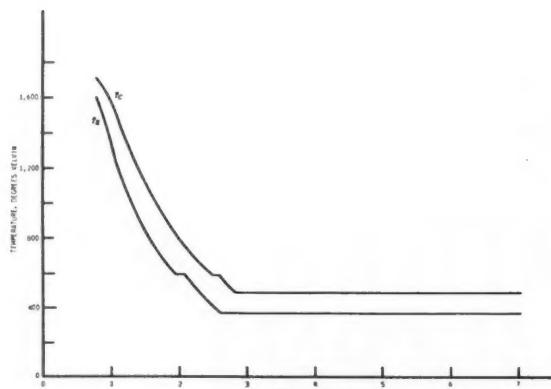
Performance Studies



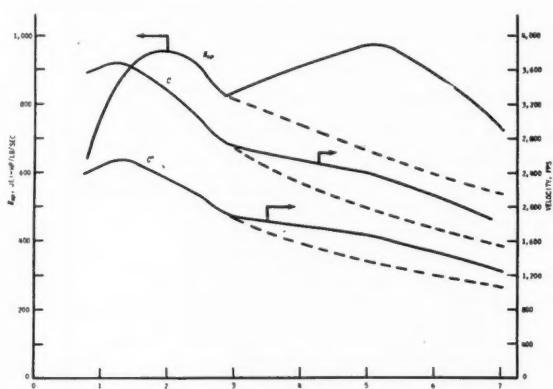
Combustion and exhaust temperature vs. mixture ratio for lithium-water system (pressure ratio 20.4).



Gas-generator performance vs. mixture ratio for lithium-water system (pressure ratio 20.4).



Combustion and exhaust temperature vs. mixture ratio for sodium-water system (pressure ratio 20.4).



Gas-generator performance vs. mixture ratio for sodium-water system (pressure ratio 20.4).

the end of the program, cavitating venturis were used very successfully to provide a constant flow of both fuel and oxidizer, irrespective of the combustion-chamber pressure.

Many different types of injectors

were investigated early in the program. A fuel-on-oxidizer multiple-impinging jet injector with an enzian-ring splash plate, illustrated below here, showed considerable promise, but the small fuel orifices became clogged quite

easily by foreign material or cooling in the fuel passages. Also, a small misalignment or deviation of the jets would cause a rapid burnout if the molten fuel hit a steel part before reacting with the water.

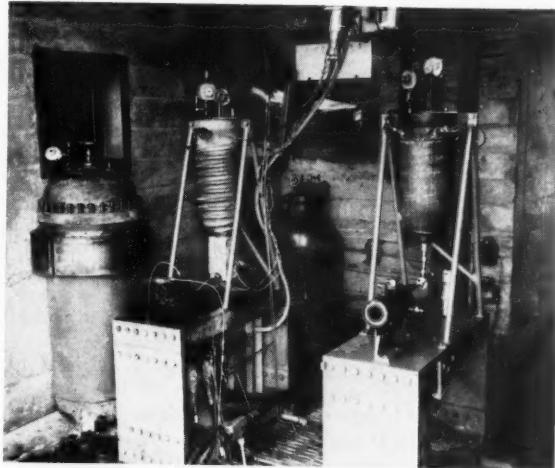
The final design of the combustion chamber, in the bottom photo, coped with these two problems by using a single fuel orifice with a swirler to produce a hollow-cone spray. A series of tangential orifices formed a moving water wall for the fuel to impinge upon and at the same time protected the steel parts, since there was always water between the fuel and the chamber wall. An enzian ring forced the excess water away from the wall into the hot flame core, which promoted mixing and the more rapid attainment of the equilibrium temperature in the downstream portion of the combustion chamber.

This design worked very well with sodium, but with lithium it required a modification. Because of the lower reactivity of lithium and the higher proportion of water needed to obtain the same final temperature, part of the water was introduced through a separate injector counter to the main flow, as shown in the bottom drawing on this page. This created a hotter primary reaction zone, and also produced the more vigorous mixing required by the larger quantity of diluent water.

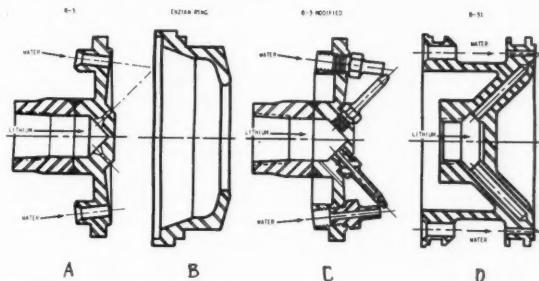
Several hundred combustion tests were made in the course of this investigation, most of them at chamber pressures between 250 and 350 psi, yielding 400 to 600 jet-HP. Many of the tests lasted only 20 to 30 sec—long enough to evaluate combustion-chamber design changes and mixture-ratio variations. A smaller number of tests ran 2 to 3 min to check the endurance of otherwise proven designs.

The impinging-jet injectors had a combustion efficiency of about 80%, as determined by the ratio of measured to theoretical characteristic velocity (c). The injector that sprayed a hollow cone of fuel against a curtain of water gave about 90% of theoretical c , and the counter-flow water spray, added in adapting the system for lithium, increased the combustion efficiency to about 95%.

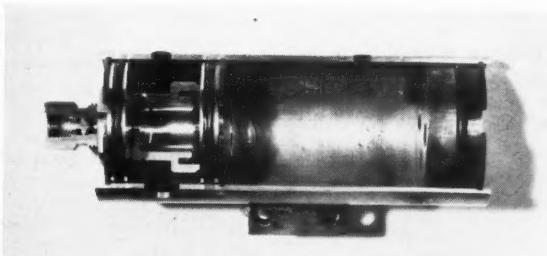
This system has certain obvious inherent disadvantages, such as fuel preheating, the nature of the reaction products, and low density, which reduces performance considerably on a volume basis. But in certain applications, where specific fuel consumption is of primary importance, these troublesome aspects can probably be tolerated, and the use of molten lithium as a water-reactive fuel can result in a superior propulsion system.



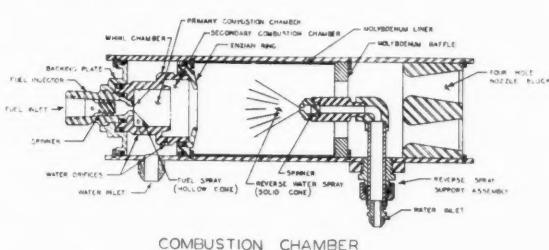
Test cell set-up.



Multiple-impingement injector.



Sodium-water gas generator with hollow cone fuel and tangential water injectors.



Lithium-water gas generator with reverse water spray.

New Shapes for Glass Fibers

(CONTINUED FROM PAGE 35)

Along with the increase in emphasis on improved structural properties for missile and space-vehicle applications, there have been a number of improvements in the characteristics of plastic materials themselves. New resins such as the epoxy types have been developed. New forms of high-modulus fabric reinforcement, unidirectional webs, and specially treated rovings have been offered. A variety of auxiliary agents for improving the interaction between glass and resin are now available. Techniques such as filament winding have become important. Resin treatment of freshly spun fibers shows promise. A new type of glass with almost double the modulus of earlier materials has also recently become available.

Are all of these developments, however, most suitable for flight structures? Or is cost still directing the evolution of plastics technology?

If an analysis is made to evaluate the relative merits of improvements in various properties of materials for missile and space-vehicle structures, two not surprising (but not self-evident) results appear: (1) Of primary importance to the vehicle is its structural weight, and (2) the property that more significantly than any other influences the structural weight is the material density. Clearly these conclusions do not mean that improvements in strength or stiffness are not valuable, since advantage can often be taken of them to provide weight reduction. More weight can generally be saved, however, by a decrease in density with no loss in strength than by a corresponding increase in strength with no increase in density.

Density decrease is most effective for increasing the structural efficiency of thin compression members, such as occur in many places in the shells of boost vehicles. Surprisingly, little effort has been aimed directly at the reduction of material density. Noting that structural plastics especially need improvement in compression, as they have not shown here the favorable strengths that they have in tension, we conclude that *an important new direction is toward density reduction without a corresponding loss in strength*, particularly for compressive loadings.

The high strengths already achieved by currently available plastics are the culmination of a number of technological developments which also yield clues about likely further developments. What are some of the

factors contributing to the success of present reinforced plastics and possible improvements in them?

The high strengths of currently available reinforced plastics have been achieved by giving careful attention to the selection of the resin and glass-phase composition, the surface treatment of the glass, and the collimation and packing of fibers.

There can be no question but that the high tensile strength of glass-reinforced plastics depends on the high tensile strength of the glass fibers. We see, for example, that in a sample made with unidirectional filaments a tensile strength of over 100,000 psi may be measured along the axis of the fibers and less than 3000 psi in the transverse direction.

The tensile strength of a reinforced plastic made with a particular glass fabric can be higher than that of the fabric itself. The reason for this is simply that in the "dry" cloth the load is not distributed evenly among the glass fibers. In the composite structure, shear interactions among the fibers induced by the resin promote a more uniform stress distribution.

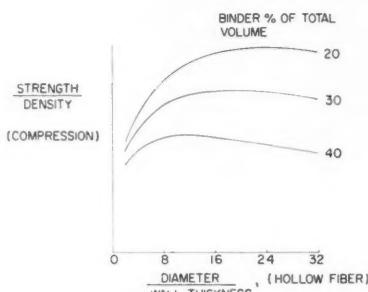
To achieve the highest tensile strengths, it is clear that the glass content, the degree of collimation of the fibers, and the shear interactions must be as high as possible. An ordinary woven-glass fabric fulfills none of these conditions because of the crimp in the yarns and the nonuniform distribution of the fiber. The industry, however, now offers fibers in distinctly superior forms. For example, an "unwoven" fabric is described by a French concern, unidirectional mats are offered by Minnesota Mining and Mfg. Co., and all of the filament-winding technology is based on the principle of fiber collimation. Not only do these developments lead to better tensile stress distribution, but also they allow higher glass contents, because of the packing that is possible with collimated cylinders.

The role of the resin is mostly the promotion of shear coupling between fibers. Even with the best packing of fibers, the shear in the resin is far from uniform. Improvements in coupling have been effected by various techniques for improving the wetting of the fibers by the resin. One of the outstanding results has been achieved by coating the glass fiber with resin while it is being formed from the melt at the bushing. This early coating tends to protect the glass from damage, as well as to provide better wetting and to improve collimation in the plastic. All three actions produce a better tensile strength.

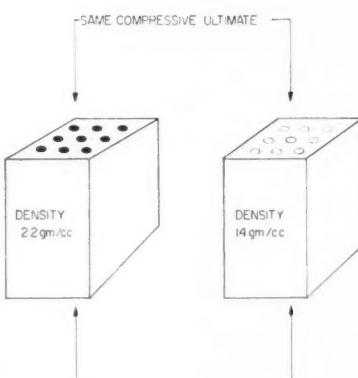
Although epoxy resins generally yield the highest strengths with glass-cloth laminates, with well-collimated fibers there is little difference between the tensile strengths of polyester and epoxy composites. Thus it would appear that good collimation is of first importance; and if good collimation is achieved, then the resin properties become less critical.

The ultimate in glass content with fiber collimation has clearly not been achieved. The theoretical maximum volume fraction of cylinders in a matrix is 91%. The observed volume fraction is generally less than 74%. One important source of this discrepancy, is the fact that multifilament rovings are used to produce the so-called filament-wound specimens. While the packing of the rovings may be quite efficient, the packing and dispersion of the separate filaments in the roving must be relatively inefficient.

An obvious way to improve packing is by true filament winding, that is, the careful layup of individual filaments. Perhaps it would be more practical, in that it would not involve so much new glass technology, to



Typical compressive strength/density ratios for composites made with hollow fibers of various diameter-to-wall-thickness ratios.



Experimental results give approximately the same compressive strengths for samples having solid and hollow-fiber glass reinforcements.

make a multifilament ribbon, in which twists and crossovers of filaments are carefully avoided. This would also permit efficient packing.

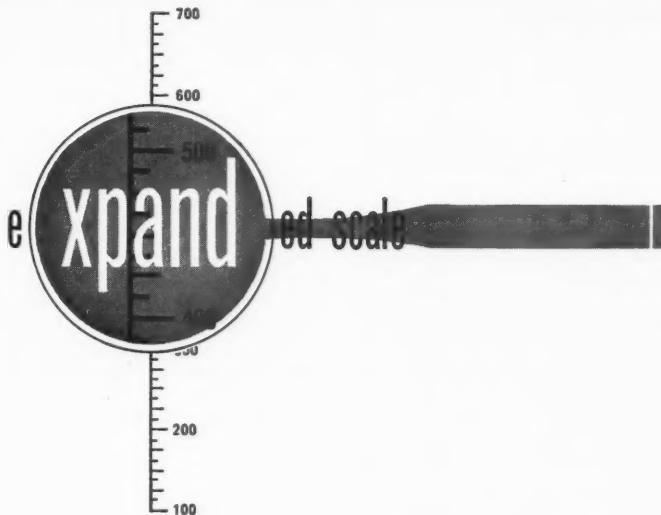
The degree of success of any process for the improvement of collimation, packing, and dispersion can be studied directly by microscopic techniques. So far, only rather casual observations of this type have been reported.

Stronger composites might also be possible if higher-strength fibers were used. The glass fibers of commerce are already among the strongest materials known. However, some work has shown that the strength of a glass fiber is strongly dependent on its diameter. The size of the commercial fibers (0.0003 in.) is in a range where doubling or tripling strength might be possible by reducing the diameter. It has been stated that strengths of 1.5 and 2.0×10^6 psi are accessible. These are higher strengths than have been achieved with any other known material, including "whiskers."

Let us ask why such a simple possible solution as reduction in diameter to increase strength has not already been exhausted. In the first place, fibers now in use are stronger than steel, and in many applications tensile strength is adequate. Secondly, the usual size of glass fibers is about the same as that of cotton. One may surmise that a reason for this is that the new glass fibers could then be handled on equipment designed for cotton. Thirdly, the cost of glass fibers does not depend on raw material costs as much as on manufacturing costs. Thus, a reduction in filament diameter by a factor of 10 might increase end costs a hundredfold; and probably the cost has been a major consideration.

Finally, there is some controversy about the reality of the size dependence of strength. A great deal of current thinking about superstrength materials involves the exploitation of the "size effect." On the basis of most recent data, it seems likely that such effects are real and substantial.

Still with reference to glass, if one used filaments with flat, square, or hexagonal rather than round cross section, composites with somewhat higher glass content would be possible. More important, shear-strain heterogeneity in the matrix (which is very serious with cylindrical fibers) would be much lower. Of course, very careful attention would have to be given to the orientation of the ribbons or prisms. Some work with flat glass flakes has already been done, and mica has always been an important filler. However, the observed tensile strengths have always been undistinguished, indicating, it is likely,



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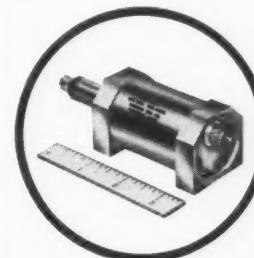
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that the orientation problem has not yet been solved. Continuous ribbons might be much easier to orient than flakes.

The small "flake" or ribbon glass approach is also interesting because of the possibility of generating high biaxial strengths. A processing breakthrough which would lead to sufficiently perfect orientation with flat reinforcements would have a high payoff. The literature indicates that only very primitive processes have been attempted.

One currently important glass development is high-modulus beryllium containing glass. Even though higher tensile strength is not claimed for this product, it might well lead to higher tensile composites, because the strain imposed on the resin would be reduced and matrix failure would be less likely to occur.

Of course, the fiber component need not be glass. Superstrength whiskers have been considered in a very primitive way. Unless continuous filaments of the whisker type could be produced (and no technique for doing this has yet been proposed) the orientation problem mentioned in connection with glass flake would still be present, in an even more aggravated form, since fibers have less symmetry than flakes. It should be noted here that high-strength composites have never been made from short glass fibers or glass wool.

With respect to resin improvement, the most useful changes that would be reflected in tensile-strength tests would be higher resin modulus and elongation. Organic materials with moduli significantly higher than those now in use are not known. Furthermore, the usual price of high modulus is low elongation, and this seems to be an even more serious problem than modulus. Resin studies might well be considered, but, on the basis of current knowledge, not in connection with tensile-strength improvement.

Many of the same considerations apply to the improvement of the compressive strength that apply to tension. That is, high volume fractions of fiber and good fiber collimation and dispersion are desired. The correlation between fiber strength and composite strength that exists in tension, on the other hand, is not applicable in compression. In fact, it is in the regime of compression loadings that present-day, oriented-fiber reinforced plastics, which have such a fine combination of high strength and low density in tension, fail to be competitive with other materials.

While the mechanics of failure of reinforced plastics in compression have not been thoroughly explored, and are imperfectly understood, there are two

factors which operate to affect the strength in compression adversely: (1) When the composite is in compression in the direction of oriented fibers, the high Poisson's ratio of the binder relative to that for the fibers creates a tensile stress on the bond between fibers and binder which tends to produce internal separation failures between them; and (2) the compressive load is carried by the fibers as columns supported within the continuous elastic foundation provided by the binder, and thus the strength is limited by the stability of these columns rather than their strength.

An approach which appears promising for improving compressive properties of fiber-reinforced composites is through the use of hollow fibers. As the fibers are hollowed out, the column stability of the fibers is increased. Moreover, the density of the composite is simultaneously reduced. Unfortun-

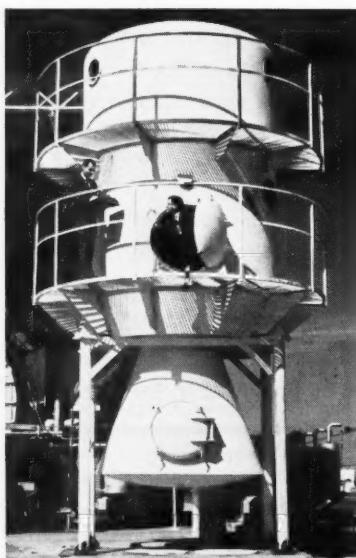
ately, the ratio of fiber content to binder is also reduced. There is therefore an interplay among the various factors affecting the load-carrying capacity of the composite. It appears that, for representative fiber and resin densities, an optimum may be found in the range of fiber diameter to wall thickness ratios between 10 and 25, as indicated by the graph on page 80. With their increased strength and decreased density, hollow-fiber reinforcements appear to lead precisely along the desirable new direction for composites.

The general idea of using hollow glass fibers as reinforcements in plastics seems to have first been given by Horridge in England in 1954. Later, George Hoffman at Rand noted the attractive possibilities of this approach. Now that semi-production quantities of hollow glass fibers of good quality have been made, and the reinforced-plastics art has advanced to its present stage, the potentials they were seeking should be available. Accordingly, some preliminary preparation of small sample hollow-fiber composites with resin have been assembled. Even though these handmade samples have not achieved perfect packing, as can be seen from the photo on page 35, tentative measurements confirm that with collimated glass fibers, solid or hollow, having an outside diameter of 0.005 in., the compressive ultimates are approximately independent of over-all density in the range from 2.2 to 1.4 gm/cc, as indicated by the sketch on page 80.

If corresponding strengths can be achieved in large pieces, the structural weight reduction that can be accomplished with this new material in a plate under compression is comparable to that achievable by a fourfold increase in modulus or strength at the same density. In addition, the new low-density material can be expected to have significantly lower dielectric constant and electrical loss factor. This could be an important advantage in radome structures.

Two somewhat independent approaches have been brought together in this study. One involves the identification of reduction in material density as a primary goal in the further development of structural materials. The second involves the manipulation of the shape of the reinforcements in a composite in such a way as to achieve the desired objective. Much of the rather highly evolved reinforced-plastics art is completely applicable to these concepts, as shown by results obtained with hollow-fiber reinforcement—the first example of what can be done through the application of these approaches. ♦♦

Space Outpost On the Ground



Manned tests are scheduled to start late this year with this full-scale space-station simulator nearing completion at Convair Astronautics. Designed for three men, the capsule will be used to develop life-support systems. It connects with a 35-ton high-vacuum chamber, which can be seen in the background. A space station of this kind has been proposed by Kraft Ehricke as an intermediate step between one- or two-man short-term orbiters and large-scale manned lunar exploration spacecraft (see "Manned Outposts in Space," page 20 in the August 1959 *Astronautics*).

Applications of Materials

(CONTINUED FROM PAGE 26)

sented by Adams.⁶

The evolution of a gas may come about through thermal decomposition of a plastic material, boiling, or sublimation. Usually, the temperature of the evolved gas is considerably lower than the main-stream gas temperature. The gas then cools the boundary layer, resulting in a net decrease in the heat flux to the solid body. The evolution of gas also thickens the boundary layer, which also tends to decrease the heat flux into the solid body by decreasing the heat-transfer coefficient. Thus, a material which generates a large volume of gas is desirable.

The effectiveness of the gas as a coolant depends to a large extent on the amount of energy it absorbs while being heated as a gas. The total heat-absorbing capacity also depends on the energy absorbed by the gas during its formation. This energy of formation is all the heat which goes into latent heat for melting and subsequent boiling or sublimation, plus the heat of formation if the gas is formed from a chemical-decomposition process.

A liquid melt-layer results when the surface material melts to form a highly viscous liquid. The thermal protection resulting from the presence of the liquid arises from the energy absorbed by the material during the melting process and from the insulating effect of the melt layer. The temperature of the solid-liquid interface is fixed by the melting process, although the temperature at the outer edge of the melt is generally higher. Energy is absorbed by the liquid when its temperature is raised above the melting point. If the temperature at the outer edge of the melt is high enough for boiling to occur, then the additional beneficial thermal effects resulting from boiling are obtained.

Effective Heat of Ablation

The effective heat of ablation is defined as the ratio of the heat-transfer rate to a nonablating surface to the rate at which material is lost from the surface on a mass basis. Because the protection offered by the ablation process depends on interactions between ablation products and the hot gas, the effective heat of ablation is a function of gas temperature and composition.

However, the point of primary interest in this discussion is that, the heat flux is a predominant factor influencing the performance of an ablative material. Therefore the chamber pressure can be more important than the flame temperature. This importance

of heat flux is similar to the case of a hot structure that has not yet attained thermal equilibrium.

Environmental Criteria

The interior surface of a rocket nozzle is exposed to a high-temperature, chemically reacting, high-velocity, abrasive flow of combustion products that is intimately related to the properties of the propellant employed. The environmental factors which affect nozzle performance may be divided into three groups, namely, thermal factors, chemical factors, and physical factors. Complex interrelationships among these factors are generally involved in the deterioration of a nozzle surface.

The table on page 26 summarizes some of the salient features of the nozzle environment. The Materials Advisory Board has estimated that nozzles will have to handle combustion temperatures of about 8300 F in the period 1970-1975.⁷

The heat flux to a nozzle throat depends on both the chamber pressure and the enthalpy of the combustion products. In addition, condensed exhaust products affect the heat-transfer processes, primarily by forming an insulating layer between the structure and the gas stream. Nongaseous exhaust products result from the addition of metals to fuels. Numerous metal additives are being considered for future propellants.⁸

Thermal conditions vary significantly along the length of a nozzle. The graph on page 25 shows the manner in which heat flux varies as a function of axial distance in a nozzle.

The chemistry of the expanding gas in a rocket nozzle is not completely understood, owing to the complex composition of solid propellants and the lack of high-temperature kinetic data. The gas consists of a large number of compounds, and the combustion process may still be going on during expansion in the nozzle. Furthermore, the equilibrium composition is changing as the static temperature and pressure decrease. Then, too, the extent to which the exhaust products approach equilibrium at every place during expansion is not known, because neither the reactions occurring nor the kinetics of these reactions are known accurately.

A number of studies of the flow of reacting mixtures are in progress. In addition to the difficulties associated with defining the gas composition, there is a further difficulty because the gas may react with the interior surface of the nozzle. Reactions with the interior surface of the nozzle are of primary interest in this discussion.

Laboratory studies of surface reactions influencing nozzle perform-

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ance are hindered by the complexity of the mixture and the fact that, even if a particular species does not appear as a reactant, it can act as a catalyst. There is reason to believe that the presence of a molten oxide layer on a surface affects the chemical reactions. It would tend to separate gas species from the nozzle surface, thus reducing gas-solid reactions, if the molten layer is sufficiently dense. The oxide may also act as a catalyst, which may be undesirable. It is difficult, if not impossible, at the current state of the art to define all of the specific reactions which can produce harmful effects on nozzle performance. Consequently, the compatibility of each surface material with each chemically active exhaust product species must be studied. The possibility of catalytic action on each of the reactions should not be neglected.

The exposure conditions associated with future propellants will undoubtedly be more severe than those now encountered. These new fuels will introduce higher heat fluxes, associated with higher flame temperatures, and also greater chemical reactivity in the exhaust gas. For example, the introduction of fluorine into solid propellants, as discussed by Farber,⁹ will both raise flame temperatures and introduce additional highly reactive chemical species into the combustion products.

Materials Development, Utilization

In a composite nozzle structure, several classes of materials are generally used, each material performing the function for which it is best suited. The choice of material depends largely on the tasks which must be performed: Load carrying, heat absorption, insulation, erosion, resistance, chemical protection, ablative cooling, etc. Only after the task or tasks have been identified can the best class or specific material be identified.

Graphite. Graphite is a "work-horse" material in high-temperature applications. It sublimes at a temperature of about 6700 F, which is higher than most materials. It is not a very strong material at low temperatures, but its strength increases with temperature up to about 4500 F. At high temperatures, graphite is considered a strong material. Graphite has a tendency to oxidize exothermically at relatively low temperatures. It has found wide use as a nozzle-insert material when the exhaust products are generally reducing. The brittleness and high thermal-expansion coefficient of graphite lead to design difficulties when it is employed in a composite structure. Some of the design problems encountered with

graphite are discussed by Krochmal and Anthony.¹⁰ The high sublimation temperature of graphite and its relatively high specific heat and high latent heat of sublimation make it attractive as a heat-sink material. In addition to its thermal properties, graphite has a relatively low density (2.25 g/cc), which tends to make it attractive for flight applications.

A vapor-deposition process of fabricating graphite has led to the development of a graphite coating with anisotropic thermal properties. This development—pyrolytic graphite—may eventually have an important effect on nozzle design in the near future. The thermal conductivity of pyrographite along the surface as formed is an order of magnitude greater than its thermal conductivity in the normal direction. The high-temperature region can be limited to a thin layer near the surface, reducing insulation requirements. It is possible that conduction of heat along the surface can appreciably reduce heating below the surface at a region of high heat flux by providing a heat-leakage path to a region of lower heat flux.

Due to its anisotropic thermal expansion, there are still many problems concerning the use of pyro-graphite. Also, many early rocket-firing tests were hampered by inconsistent coatings. When one designs with pyrographite, its anisotropic thermal-expansion properties must be considered. As experience in the use of the material is gained, it will probably find many applications in rocket nozzles.

Refractory Metals. A few important metals that are among the most refractory materials available are tungsten, tantalum, and molybdenum. The refractory metals have high tensile strength and good resistance to thermal shock when compared with most ceramic materials. The high density of these metals limits their use in nozzles to specialized applications, such as throat inserts. As with other metals, the refractory metals suffer from a loss in strength at temperatures approaching melting point, and this limitation becomes important because throat-insert materials must operate at near-melting temperatures. Structural and fabrication problems sometimes become severe—particularly the brittleness of molybdenum, the difficulties encountered in fabricating large parts of tungsten, and the poor thermal-shock resistance of tungsten. Alloys of the refractory metals have been used to obtain a reasonable compromise between ease of fabrication and high-temperature properties.

Tungsten, with a melting point of 6160 F, is widely used in the high-temperature region of nozzle struc-

tures. The high density of tungsten and difficulties in fabrication have led to its use only in critical nozzle regions, such as the throat. Dense, forged sintered tungsten is available. Thin, hot-spun tungsten nozzle forms have also been fabricated.⁵ The current need for tungsten parts has stimulated development of forming methods. At present, high-temperature physical and thermodynamic property data are limited. Additional data are needed above 3000 F so that this material can be utilized to its full potential in nozzle designs.

Ceramics. The metal oxides have high melting temperatures, although not quite as high as tungsten. The metal oxides are brittle and more susceptible to thermal shock than are most metals. The densities of the ceramic oxides are considerably less than those of the pure refractory metals.

Metallic compounds, such as the carbides, nitrides, and borides, are similar in many respects to the oxides, with the exception of their chemical stability. The metallic compounds are sometimes referred to as the hard metals, because of their high conductivities and metallic luster in addition to hardness. Whereas the oxides are usually stable in an oxidizing environment and unstable in a reducing environment, the opposite is usually true for the carbides, nitrides, and borides.

Melting Points

The melting points of the metallic compounds are not necessarily as high as either of their constituents. For example, tungsten carbide has a melting point of about 4710 F, whereas pure tungsten melts at about 6160 F, and graphite sublimes at 6700 F. This effect of depressed melting point is one that is commonly encountered. On the other hand, hafnium carbide and tantalum carbide both melt at temperatures higher than 7000 F. However, the former is extremely expensive, and the latter has a high density and an unusually strong tendency to oxidize.¹¹ A number of carbides and nitrides offer the possibility of operation at temperatures of the order of 7000 F. The promising materials are generally highly susceptible to thermal- and mechanical-shock failure. Their limitations can probably be overcome by the development of composite materials.

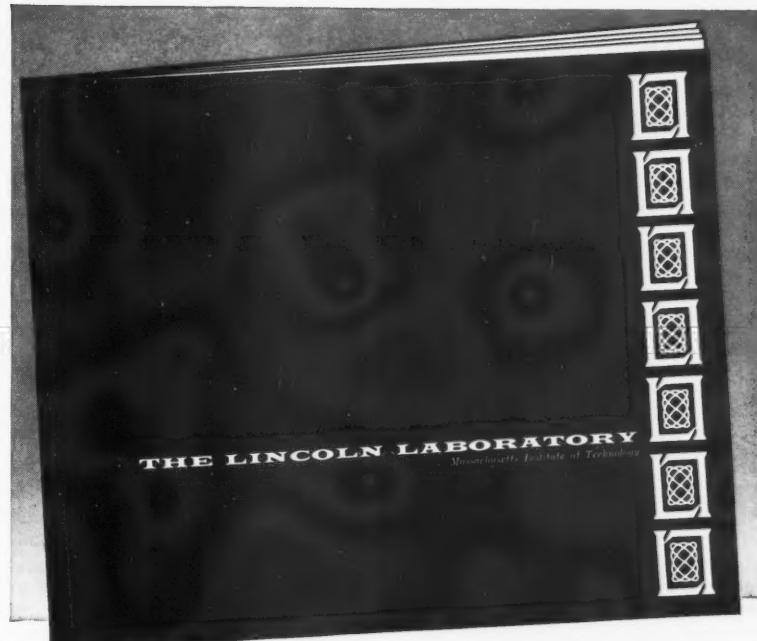
Composite Materials. The same specialized applications which have led to the use of the composite nozzle structure have also led to the current interest in composite materials for applications within the structure. The

composite-material concept permits materials to be designed which satisfy particular needs. A composite material may incorporate a ductile material and a refractory brittle material to achieve a combination that will withstand both the thermal shock and the high temperatures associated with a rocket-engine firing. The Avcoite family of materials, described by Scala,¹² is typical of this type of composite. These composites incorporate a brittle refractory in a metal honeycomb. It is believed that the composite-material concept will be needed in order to utilize the high melting temperatures of some carbides and nitrides.

A second form of composite material is being applied in ablation systems. The performance of an ablation material depends to a large degree on the cooling capacity of the ablation products, rather than on the high-temperature properties of the solid material. Hence, the desirable ablation materials are those which produce large quantities of gas, preferably with a low molecular weight, and/or viscous melt-layers. Therefore, the most commonly used ablation materials are composites of glass-like materials and plastics resins.

Common resins are the phenolics, melamines, silicones, epoxies, and polyesters. The glass is generally used in fiber form, and various glassy materials have been used in ablating composites. They improve the strength characteristics of the composite material. A large number of material combinations are now available under a number of trade names. The recent introduction of graphite cloth on the market has lead to the consideration of impregnated graphite cloth as a nozzle material.

Values of the effective heat of ablation, ranging from about 1000 to about 6000 Btu/lb, are now attainable. The reason that ablating materials are not applicable to the high-heat-flux, long-time exposure obtained in the throat of a rocket engine can best be illustrated by a simple example. Consider a material with an effective heat of ablation of 2000 Btu/lb and a density of 100 lb/cu ft. This material may be considered to be representative of the general class of ablating reinforced plastics. It is also reasonable to assume a heat flux in a nozzle-throat region of the order of 20 Btu/sq in./sec. Thus, a linear erosion rate of about 0.17 in./sec would be obtained with this material, if it were used at the nozzle throat. If the burning time was of relatively long duration, or the nozzle diameter small, the total throat erosion would be intolerable. On the other hand,



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if a short-burning-time application is considered, then the application of an ablating material may be permissible in large nozzles.

Reinforced-plastic composites usually have a low thermal conductivity besides a low density, which make them useful backup insulation in hot structures. Further, when used in ablative structures, the reinforced plastic can provide both the ablative surface and the thermal insulation required to protect the structural shell. Thus, refractory materials may not be required for the shell in either case, and steel and titanium become logical choice because of their high strength-to-weight ratios.

Future Development Requirements

The problems involved in the development of uncooled nozzles are intimately related to the nature of the exhaust products. The velocity increment delivered by a rocket stage increases approximately linearly with propellant specific impulse and as a logarithm of $1/1 - m_f$, where m_f is the propellant mass fraction (propellant weight/total weight). Some loss in mass fraction may be acceptable to take advantage of improved propellants. But there are limits to the mass-fraction losses that can be accepted without compromising performance to the point where new propellants are not worthwhile. Therefore, continued nozzle improvements are warranted.

The present nozzle-design philosophy is based primarily on the modified hot-structure concept. Nozzle requirements during 1965-1970 will require either that the exposed element of the hot structure be more refractory than the refractory metals or that the structure provide more heat sink than is now provided. Advances in the area of composite materials containing extremely refractory ceramics will determine which philosophy will be adopted. An alternative philosophy, namely, that of the cooled structure, might be utilized in the 1965-1970 period and will probably be required in the 1970-1975 period. The cooled structure can use either a passive coolant on the back surface of the exposed material or an active coolant which is injected through a porous nozzle surface.

Advances in materials and nozzle-design technology will be necessary to use to advantage advanced propellants. There is need for additional research on exhaust-product environments and expansion processes, on composite materials which utilize constituents more refractory than tungsten, and on improved ablation materials. Moreover, we need improved high-temperature-property data for

the materials now available to permit their more effective utilization.

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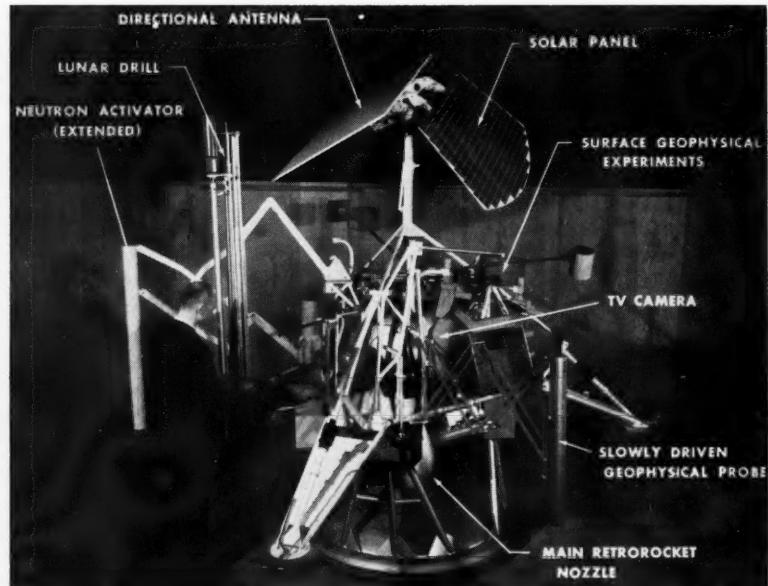
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In January, NASA made its first award under the invention authority of the National Space Act of 1958 to Frank T. McClure, chairman of the Research Center at Johns Hopkins Univ. Applied Physics Laboratory, Silver Spring, Md., for his invention of the Doppler navigation system which became the basis for Project Transit. The award was for \$3000.



Surveyor Lunar Soft-Lander To Be Built by Hughes

JPL unveiled this model of the Surveyor lunar soft-landing spacecraft shortly after the selection by NASA of the Hughes Co. to build it. NASA plans call for seven Surveyors to be launched to the moon in the 1963-65 period. Surveyor will weigh about 2500 lb when injected into a lunar-impact trajectory, and 750 lb when landed on the moon after retrorocket firing. Of the landed weight, 200 lb will be working instruments.

ASTRONAUTICS Data Sheet — Propellants

Compiled by Stanley Sarner, Flight Propulsion Laboratory Dept., General Electric Co., Cincinnati 15, Ohio

TETRAFLUOROHYDRAZINE



Tetrafluorohydrazine is a relatively new cryogenic oxidizer, synthesized recently as a result of expanded oxidizer research. Both the liquid and gas have been described as colorless. The oxidizer is stable and, although not storable, may find considerable use as an intermediary in producing new oxidizers, and also may provide improved handling ease when used instead of oxygen or fluorine in rockets.

Hazards

N_2F_4 has been reported to persist in dry air for a considerable time, and even in moist air for several minutes. Since no extensive toxicity tests have been made, the material should be treated in the same manner as fluorine.

Materials for Handling

Very little information is available here. It is known that glass, stainless steel, and copper are not attacked at room temperature. Here again, materials suitable for fluorine use should be satisfactory.

Properties of Tetrafluorohydrazine, N_2F_4

Boiling Point, C	-74 ± 1
Freezing Point, C	-162 (approx)
Critical Temperature, C	37.5
Critical Pressure, atm	54
Vapor Pressure, mm	$\log P = 6.9643 - 811/T$
Density (at -100 C), g/cm³	1.5
Heat of Vaporization, kcal/mole	3.170
Heat of Formation (gas at 25 C), kcal/mole	-2.0 ± 2.5

Theoretical Performance of N_2F_4^*

Specific Impulse (sec)		Chamber Temperature	
	Frozen Flow	Equilibrium Flow	(Deg K)
N_2H_4	311	332	4431
H_2	326	357	—
NH_3	306	325	—
UDMH	286	316	—
JP4	277	297	—

* $P_c = 1000 \text{ psia}$; $P_e = 14.7 \text{ psia}$; optimum O/F ratio.

Cost and Availability

Only small quantities are available presently at a cost of approximately \$100/lb.

lb. Higher production rates would probably drop the cost down to near that of fluorine.

DIETHYLENE TRIAMINE (DETA)—($\text{H}_2\text{NC}_2\text{H}_4)_2\text{NH}$

DETA is the lowest member of the polyalkylene amine series and may be considered as the dimer of ethylene diamine. It is rather hygroscopic and will absorb moisture upon exposure to a humid atmosphere. DETA has been considered mainly as a propellant additive in order to "tailor" physical properties.

Hazards

DETA is flammable, but not pyrophoric. It is a much stronger base than UDMH and will cause caustic burns of the skin upon extended contact. Its LD₅₀ values (dosage which kills 50% of test animals) are fairly high. For oral doses the value is 2.33 g/kg as compared to 0.35 g/kg for ammonia; for skin absorption (24-hr contact), 1.09 ml/kg (1.04 g/kg) as compared to 1.1 g/kg for ammonia. No animals (of 6) were killed after 8 hr of inhalation of saturated vapors, while 2 (of 4) animals were killed in 1 min of inhalation of the saturated vapors of 28% ammonia in water. DETA appears to be less toxic than ammonia, and also less hazardous due to its lower vapor pressure.

Materials for Handling

Stainless steel (304, 347, etc.), monel, nickel, and aluminum (2S) are satisfactory; mild steel is sufficient for short-term storage. Copper and copper alloys

Physical Properties of DETA

Boiling Point	206.7 C	404.1 F
Freezing Point	-39 C	-38 F
Density at 25 C (77 F)	0.950 g/cm³	59.3 lb/ft³
Viscosity at 15 C (60 F)	8.2 Centipoises	—
Vapor Pressure at 100 C (212 F)	0.026 atm	0.38 psia
at 180 C (356 F)	0.500 atm	7.35 psia
Flash Point (open cup)	102 C	215 F
Heat of Vaporization at bp	12.3 kcal/mole	214 Btu/lb

Theoretical Performance of DETA*

Specific Impulse (sec)		Chamber Temperature	
	Frozen Flow	Equilibrium Flow	(Deg K)
F_2	322	330	3500
O_2	289	295	3350
RFNA	257	260	3200

* $P_c = 1000 \text{ psia}$; $P_e = 14.7 \text{ psia}$; optimum O/F ratio.

These values are approximate and should not be relied upon.

should not be used.

Teflon and polyethylene are good elastomers as well as U.S. Rubber 899 or its equivalent. Centrifugal pumps are recommended and Garlock 234 will serve as pump packing.

Cost and Availability

DETA is available in tank car lots at 41.5¢/lb; in 55 gal drums, 45.5¢/lb; and 5 gal containers, 55.5 ¢/lb, as well as in other quantities.

Carbonaceous Materials

(CONTINUED FROM PAGE 33)

tors such as composition and structure, since these influence the resin's behavior during chemical transformation. A few of the resins considered to be feasible in the aforementioned study for the basic carbon binder of the reinforced carbonaceous systems include phenal aldehydes and furfurals. These were selected on the basis of being thermosetting (to maintain shape during decomposition), having a highly cross-linked structure, and containing only C, H, and O constituents.

Reinforcement selection must be guided primarily by such factors as strength, temperature resistance, compatibility with carbonaceous binder, and availability. Fibrous reinforcement agents such as silica, graphite, refractory metals, and ceramics are all possibilities.

Many and various combinations of resins and reinforcement agents have been evaluated. Chance Vought studies show the superiority of phenolic-resin systems over other resin systems of the epoxy or silicone types. With organic-state reinforced plastic systems, "E"-glass and quartz-cloth reinforcements provided better mechanical strength properties to the carbonaceous system than a Refrasil reinforcement did.

In producing reinforced carbonaceous material systems, conventional reinforced-plastics technology is employed to fabricate the cured solids, while the final carbonization processing is similar to that employed by the carbon and graphite industry. This process permits retaining the relatively

low cost, ease of fabrication, and configurational variety of plastic constructions.

Efforts to date have resulted in a lightweight (0.081 lb/in^3) fiberglass-reinforced carbonized phenolic-resin material having, for example, a tensile strength of 9900 psi in an oxidizing atmosphere at 1100 F. For higher temperature environments, quartz-reinforced carbonized phenolic-resin laminates provide tensile strengths of 7500 psi up to temperatures approaching 1500 F. Of particular interest is the fact the quartz system, once converted, offers promise of a consistent strength level over the temperature range of 75 to 1500 F.

These strength values, even at this early stage of development, are higher than those obtainable by the presently known reinforced organic-plastic laminate systems under sustained elevated temperature conditions. By increasing the carbon content of the thermally converted laminate system, the resultant strength properties can be substantially increased. For example, a 15% increase in carbon content resulted in an 85% flexural strength increase for the quartz-reinforced carbonaceous material system. Significantly, the modulus of elasticity of the carbonaceous system, 3.97×10^6 , is considerably higher than that of the virgin system, 2.90×10^6 . This gain, however, is countered by lowered toughness.

At 1500 F the strength-density ratio of the quartz system is approximately 100,000. The presently available columbium alloys, at the same temperature, have strength-density ratios ranging from 120,000 to 240,000. Further developments in processing and materials can be expected to raise

the performance of the carbonaceous materials to compete with the refractory system. It was estimated during a recent design study of a glide reentry vehicle that such a carbonaceous material having the previously mentioned order of strength characteristics, but improved to an allowable operating temperature of 2200 F, would have provided a weight savings of approximately 100 out of a total weight of 3000 lb.

Our current laboratory efforts are now concerned with the higher temperature resistant reinforcement systems. Processes have been developed to bring carbon-cloth-reinforced phenolic-laminate systems through the carbonized state to the highly desirable graphitized state. At a level of 0.032 lb/in^3 this type of system has an attractive weight characteristic. A concerted effort is presently underway on a suitable oxidation protective coating in order that this material combination can be used in air at temperatures up to 5000 F.

Cursory examinations have been made of various other types of high-temperature-resistant random fiber-reinforced phenolic-resin systems. As can be expected, the strength levels of random fiber-reinforced systems drops significantly in comparison with the woven-cloth composites. However, it is encouraging to note that some of these systems are approaching the room-temperature flexural-strength property of ATJ graphite.

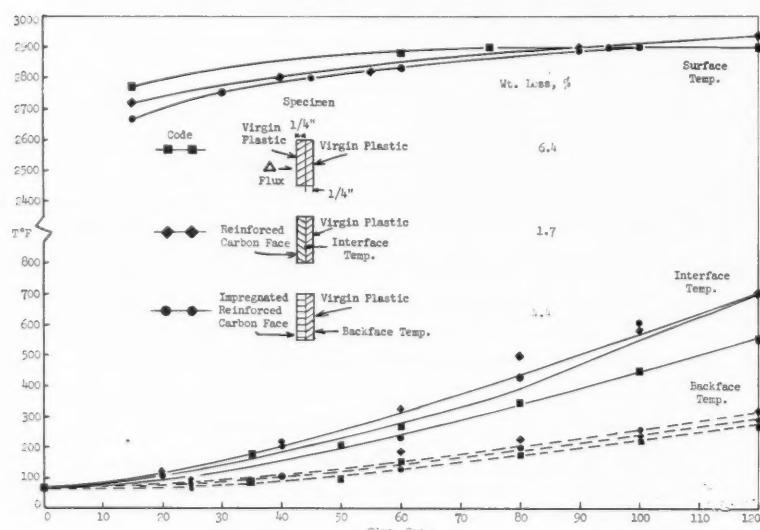
The effectiveness of reinforced carbonaceous material as a structural char layer for ablation cooling was found to be quite significant, as the graph at the left indicates. The weight losses to maintain a similar back-wall temperature are compared in the graph for the following material systems exposed to a flux density of $100 \text{ Btu}/\text{ft}^2/\text{sec}$ generated by an oxygen-nitrogen 40-kw plasma arc:

1. Virgin glass reinforced phenolic resin laminate.
2. Glass reinforced carbonized phenolic resin laminate faced virgin glass reinforced phenolic resin laminate.
3. Resin impregnated glass reinforced carbonized phenolic resin laminate faced virgin glass reinforced phenolic resin laminate.

For the third type of specimen, a melamine resin was employed as the impregnant. This resin was selected since it has an unstable aromatic structure which tends to fragmentize under heating conditions, leaving a low-carbon residue, but producing a gaseous layer for effective blocking in the boundary layer.

Confirming anticipated results, reinforced carbonaceous material faced

Precharged vs. Virgin-Plastic Ablative Systems



virgin glass reinforced phenolic resin laminate system showed little evidence of surface recession and had a loss of only 28% of the all virgin glass reinforced phenolic resin laminate system in addition to having the lowest initial weight. Although the impregnated system lost more weight than its unimpregnated counterpart, it did not deteriorate nearly as much. This would indicate that the desired blanketing effect was attained, and that with a better impregnant material, such as one of the polyethenic compounds, a more efficient system might be obtained. It is also of interest to note that the addition of the char layer significantly lessened the degree of deterioration of the substrate layer.

These results represent a beginning in the investigation of a new family of materials. Feasibility has been demonstrated. Now, studies on material combinations and processes for these types of material composites must consider the following factors:

Char Formation. As previously stated, and in agreement with other investigators, such as W. T. Barry, W. H. Sutton, and I. J. Gruntfest of GE, the effectiveness of the char in protecting the underlying virgin resin depends on its structure and also on the length of time that it is structurally attached to the resin during the ablation process. The key to attaining this thermal shield lies in a further understanding of the mechanism of char formation.

Reinforcement Agents. Reinforcement agents should be complementary to the char with respect to struc-

tural considerations as well as physical, chemical, mechanical, and thermal characteristics, such as melting point and emissivity and reactions. An effective composite will depend upon the interrelations of the charred resin and reinforcement agent toward providing a highly radiative refractory surface.

Virgin Resin Ablator. A prime requisite for the virgin resin layer is that during decomposition it act as a low-carbon-forming gas-producing agent. Rates of reaction, decomposition products, and boundary-layer reaction mechanisms should be studied to guide the proper selection of the virgin resin material.

Oxidation and Erosion Resistance. The necessity of having extreme versatility of end product is illustrated by the possible environmental conditions encompassed in the areas of rocket-motor nozzles, re-entry vehicle skin panels, or nose cones. Special processing of carbonized resin laminates must be considered to satisfactorily improve base properties, such as oxidation and erosion resistance.

We believe it will be possible to tailor an extremely wide variety of composite, reinforced carbonaceous materials. Thermal, physical, and mechanical characteristics may be designed into the end product as required. Fabrication equipment is now available with practically no unreasonable size or shape limitations. The materials engineer now has another approach to aid the designer in the solution of present and future vehicle designs. ♦♦

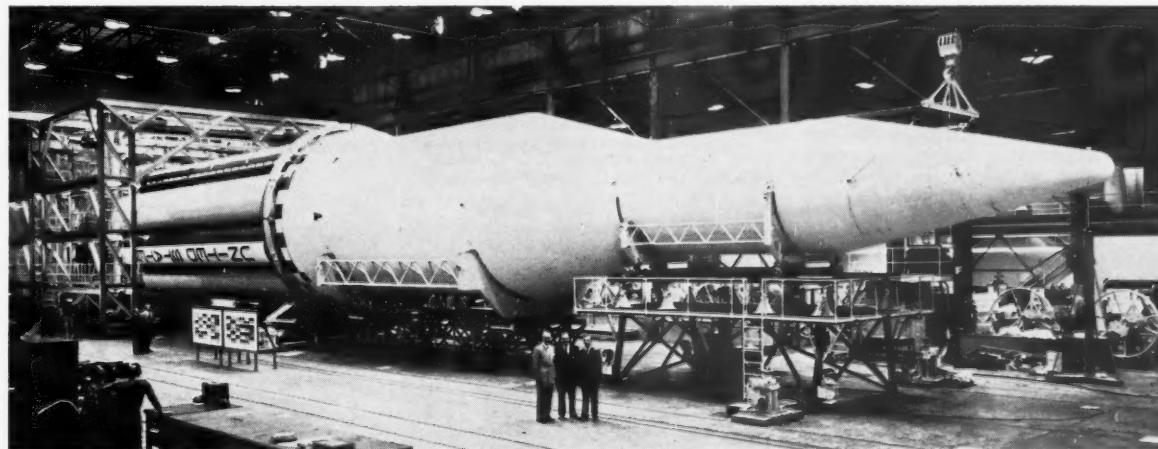
Navy Rocket Symposium

Thirty-three papers will be presented at the Bureau of Weapons-sponsored rocket symposium being held April 18-21 at the Quality Evaluation Laboratory of the U.S. Ammunition Depot in Concord, Calif. The meeting will feature talks by T. C. Merkle, U of C Radiation Lab, M. J. Zucrow of Purdue Univ., and R. C. McMaster of Ohio State Univ., among others, and will include demonstrations of QEL's new 10-mev radiographic linear accelerator, various fluoroscopic, ultrasonic, radioisotope, and eddy-current test methods, and the Adapt test and calibration machine. Arrangements for the symposium, which is expected to draw an audience of about 400 specialists, are being made by QEL, Capt. R. R. Heilig, USN, Commanding Officer.

FAA Considering Changes in Rocket Rules

The Bureau of Air Traffic Management of the Federal Aviation Agency has under consideration a proposal to amend Parts 48 and 60 of the Civil Air Regulations, dealing with operation of moored balloons, kites, unmanned free balloons, rockets and missiles. Comments on the proposal must be submitted to the Docket Section, FAA, Room B-316, 1711 New York Ave., N.W., Washington 25, D.C., by May 30, and copies of the proposed changes are available from FAA's Bureau of Air Traffic Management.

Saturn C-1 Flight Configuration



The Saturn C-1 with dummy second and third stages, lying in at NASA Marshall SFC's Fabrication and Assembly Engineering Div., brings home the scope of coming space flights, and suggests the impact they will have on the popular imagination. All stages live, the C-1 Saturn will be capable of placing 19,000 lb in 300-mi orbit, sending 5000 lb to escape velocity, and projecting 2500 lb to Mars or Venus. The first Saturn flight test, under just first-stage power, is scheduled to take place late this year.

ASTRONAUTICS Data Sheet — Materials

Compiled by C. P. King, Materials and Process Section, The Marquardt Corp., Van Nuys, Calif.

MOLYBDENUM AND ITS ALLOYS

Molybdenum was the first of the refractory metal group to be used in aerospace applications and is still the most widely used. Molybdenum's high melting point—almost 2000 F higher than that of iron—permits its utilization at temperatures where even the superalloys have exceeded their softening point. Commercially pure molybdenum is still widely used, but the addition of 0.5% titanium results in considerable improvement in its properties. A yet newer alloy, TZM, containing 0.5% titanium and 0.07% zirconium, is now becoming available.

A very high modulus, a low coefficient of thermal expansion, a low specific heat, and excellent resistance to corrosion in many mediums including liquid metals are among the other notable characteristics of molybdenum and its alloys. The biggest disadvantages of this group are high density, difficulty of welding, brittleness at room temperature, and ready oxidation.

Fabrication

Most molybdenum parts are fabricated from sheet metal. All conventional methods are applicable—spinning, deep drawing, drop hammer, and stretch forming—and are being used with success. Forming temperatures between 200 and 1000 F are usual and most blanking, punching, and shearing is done inside the same temperature range. Forging, extruding, swaging, and drawing are carried out on conventional equipment. Some parts are made by slip casting and others are sintered and machined to shape. The machining of molybdenum should be done with carbide tools. These should have similar geometry to tools used for cast iron. Tools must be kept sharp and cool. Chemical milling is also employed to advantage.

Joining

Riveting with moly rivets is the simplest way of joining inasmuch as molybdenum and its alloys are difficult to fusion weld. Adaptations of the inert gas method may be used but extremely close control over welding conditions is necessary since welds tend to be brittle. Resistance welding is less difficult and brazing can be done with silver solder, copper, nickel, or one of the high-temperature vacuum-brazing alloys which retain good strength over 3000 F.

Protection

Above 1000 F, molybdenum and its alloys oxidize rapidly in air or oxidizing atmospheres. An ideal protection method has yet to be found. However, disilicide diffusion coatings appear to be the best for most applications. Electroplating and metallizing have been used and under some conditions aluminide

and boride coatings afford satisfactory protection.

Heat Treatment

Molybdenum and its alloys do not respond to heat treatment, consequently they rely entirely on mechanical work for strengthening. However, exposure to time/temperature cycles which result in recrystallization causes a drastic reduction in strength. Instead a stress relieving treatment is normally given to reduce stresses without substantially affecting strength. Such treatments usually consist of 1800 F for 1 hr for commercially pure molybdenum and 1900 F for 1 hr for the 0.5% titanium alloy.

Availability

Molybdenum and its alloys are mostly produced by arc-casting, though sintering is used to a lesser extent. Electron-beam melting is used to produce material of very high purity and may become a more important process in the future. Available forms of molybdenum and its alloys include sheet, strip, plate, foil, bar, wire, rod, tubing, powder, forgings, and extrusions. Castings have not yet been produced.

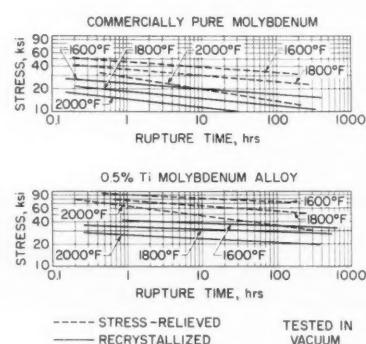
Applications

Heating elements, electrical contacts, and electrodes have long been made of molybdenum. More recently, the aerospace industry has begun to make use of molybdenum and its alloys for such components as nozzles and nozzle inserts in rockets, re-entry leading edges, guide vanes, jetavators, heat-radiation shields, turbine wheels, combustion cans, and similar parts in missiles. Ramjet engines have utilized flame gutters and combustion chambers of molybdenum, and it is certain that turbojet engines of the future will have molybdenum turbine buckets and guide vanes.

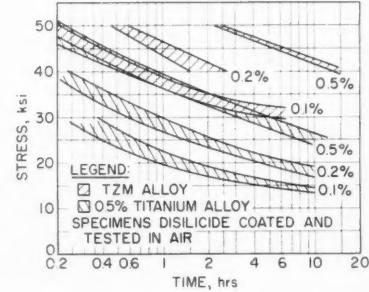
Physical Properties of Molybdenum

Density, lb/cu in.	0.368
Melting Point, F	4760
C	2625
Linear Coefficient of Expansion per deg F at 70 F	3.0×10^{-6}
Specific Heat, C/G/C	0.061
Thermal Conductivity, cal/sq cm/cm/C/sec	0.382
Elastic Modulus, psi $\times 10^6$	47

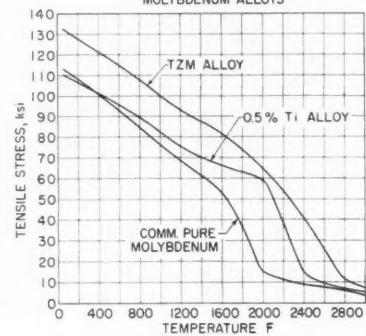
STRESS RUPTURE PROPERTIES



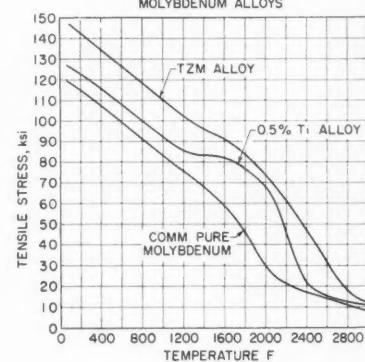
CREEP PROPERTIES OF MOLYBDENUM ALLOYS AT 2000 F



0.2% YIELD STRENGTH OF MOLYBDENUM ALLOYS



ULTIMATE TENSILE STRENGTH OF MOLYBDENUM ALLOYS



People in the news

APPOINTMENTS

Col. Thomas W. Cooke has been named commander of Redstone Arsenal, Alabama. He formerly had been AOMC chief of staff.

Col. Richard R. Entwhistle has been appointed director of the Army Ordnance Corps Ballistic Research Laboratories.

O. B. Lloyd Jr. has been appointed director of public information for the National Aeronautics and Space Administration.

Antonio Ferri has been elected president of General Applied Science Laboratories, and will continue to head the company's Aerospace Engineering and Applied Mechanics Dept.

Frank W. Lehan, chairman of the ARS Communications and Instrumentation technical committee, has been elected executive vice president of Space Electronics Corp. **Albert P. Albrecht** becomes vice president and general manager of the new Space Electronics Div., and **Jack E. Froehlich**, general manager of the Applied Science Div.

Camille M. Shaar Jr. has been appointed head of aerospace operations for the Defense Systems Div. of General Motors, with headquarters at Santa Barbara, Calif.

At Grand Central Rocket Co., **John J. Crowley** has been appointed assistant general manager; **G. R. Makepeace** has been promoted to technical director in addition to his responsibilities as vice president of research and engineering; and **Eugene Miller** is director of chemical engineering under Makepeace. **B. J. Smith** has been named assistant vice president for operations and continues as manager of the Kansas Ordnance Div., and **Chris Fitzgerald**, reporting to Smith, will be in charge of materiel handling.

L. Wayne Mullane has been elected vice president, Downey Plant, Aerojet-General Corp., and **Jack T. Wills** has been appointed to Aerojet's Washington staff as director of corporate special projects.

E. D. Carter, a member of the Senate Military Procurement Advisory Committee, has been named corporate director of materiel and procurement at the Martin Co.

Lockheed Missiles and Space Div. has appointed **James W. Plummer** to head its special satellite programs and **Walter V. Tyminski** to head military satellite programs. **Fred W. O'Green**

will serve as satellite systems assistant director, under Daniel J. Gibbon.

Sidney W. Kash has been appointed supervisor of the plasma and electron section in physics research at Armour Research Foundation.

Robert W. Mayer has been appointed manager, engineering, for General Electric's Ordnance Dept. **Alex London** has recently joined the company's Missile and Space Vehicle Dept., with senior level responsibilities for various thermal problems on projects Advent and Nimbus.

C. T. Butler has been appointed director of Hercules Powder Co.'s Chemical Propulsion Div. **Fred M. Hakenjos** and **William E. Howell** have been made directors of operations and contract administration, respectively, in the division.

Eric J. Isbister has been appointed vice president, engineering, at Radiation Inc., in charge of the company's design and development activities.

John R. Opel has been promoted to director of communications, corporate staff at IBM. He succeeds **Dean R. McKay** who was elected vice president. **Ralph G. Mark** becomes manager of the engineering laboratory at IBM Federal Systems Div.'s Command Control Center, Kingston, N. Y.

Edward Teller, associate director of Lawrence Radiation Laboratory, and **Joseph Kaplan**, former chairman of the U. S. National Committee of the IGY, have been named senior technical advisers of Geophysics Corp. of America.

Robert W. Lynch has been named chief engineer for McCormick Selph Associates.

Harold D. Germann has been appointed manager, government operations, Thiokol Chemical Corp.'s West Coast District Office.

Manfred Mannheimer has joined the Systems Research Center of Lockheed Electronics Co., and will be engaged initially on projects involving propagation, nuclear fusion, and reentry.

Daniel P. Ross has been promoted to senior engineering specialist in the Tapco Group Research Dept. of Thompson Ramo Wooldridge Inc.

Edward W. Warnshuis has been appointed manager of advanced planning at Litton Systems, Inc.'s, Data Systems Laboratory.

William C. Cleveland Jr. has been appointed assistant manager, radar and telemetry, electronics operation at Aeronutronic Div. of Ford Motor Co. **John N. Ong Jr.**, former Washington Univ. assistant professor of metallurgy, has joined the division's chemical metallurgy and ceramic section of materials.

Jesse R. Lien has been appointed general manager of the Mountain View (Calif.) operations of Sylvania Electronic Systems, and **Melvin E. Lowe** becomes manager of the operations' Reconnaissance Systems Lab. **Victor Twersky**, head of research, Electronic Defense Labs, has been promoted to senior scientist, and **Norbert J. Gamara** becomes manager, antenna research and development department, Electronic Defense Labs.

John C. Forrest and **Frank N. Gillette** have been promoted to the respective positions of director and associate director, Engineering Div., GPL Div. of General Precision, Inc.

Thomas R. Maher has been named director of manufacturing of Packard Bell's Technical Products Div.

Rear Adm. Henry C. Bruton (USN-ret.) has been named director of the Fleet Communications Div., Alpha Corp., a subsidiary of Collins Radio Co.

James F. Healey succeeds John W. Anderson as general manager, Minneapolis-Honeywell's Aeronautical Div. facility at St. Petersburg, Fla. Anderson has taken a sabbatical leave for advanced university studies. Healey has been director of advanced systems planning for Honeywell's Military Products Group. **Robert L. Crouse** has been named manager, space engineering, Aeronautical Div.

John Ross has been named manager, Research and Development Dept., Metals & Controls, a division of Texas Instruments Inc.

C. Rhoades MacBride has assumed full responsibility for Convair operations as acting president of the General Dynamics Corp. division. ♦♦



Plummer

Lehan

Expandable Structures

(CONTINUED FROM PAGE 31)

figuration to investigate problem areas and conduct preliminary evaluations near operating conditions of a space station. Use of proven escape techniques and equipment and recovery of a space station upon completion of the tests make this a simple and inexpensive program. Artificial gravity for these concepts can be supplied by rotation about the torus axis.

Expandable structures have also been considered for ballistic and lifting re-entry vehicles because of the many advantages they offer. These structures of low density and light wing-loading make it possible to increase the re-entry corridor width, while their packageability makes it possible to utilize presently available boosters for model or full-scale tests. The lower re-entry temperatures achieved with vehicles of this type alleviate environmental and structural problems, thus orienting many design requirements within the state of the art.

The second illustration down on page 31 shows a typical lift-glide re-entry vehicle in both the packaged and deployed conditions. A parametric analysis was made for wing loadings of 5 and 10 psf resulting in a maximum re-entry temperature of about 1500 F. The expandable structure consists of cylindrical and Airmat components supplemented by shear webs and cable attachments where necessary.

Unmanned Orbital Operation

A typical example of the application of expandable structures to unmanned orbital operations is the solar concentrator. Our company has pioneered the use of aluminized plastic film for an expandable parabolic reflector for spacepower generation. Methods of fabricating, packaging, deploying, and rigidizing reflectors have been considered for powers ranging up to 15 kw and for dish sizes of approximately 50 ft in diam. A 10-ft-diam demonstration model has been constructed, under contract, for evaluation purposes, as shown at the bottom of page 31. A clear plastic cover completely encloses the reflector. The shape of the reflector is attained by pressurizing the volume between the reflector and the hemispherical section. Rigidization is provided by releasing a lightweight foam between the reflector and the outer cover behind it. After sufficient time to insure permanent set of the foam, the transparent covering is cut from the periphery of the reflector and removed

for efficient reflector operation. Two- and 10-ft models are presently being built of 1-mil Mylar to improve foaming techniques and fabrication methods. The concentrator efficiencies will be checked in a specially designed GAC test stand.

In the development of expandable structures for space application, Goodyear Aircraft has proceeded using the philosophy of extending the state of the art of known reliable materials to the new environment and conditions. This involves the application of the best qualities of existing materials after evaluation and testing in the space environment, rather than development of entirely new materials, and has accelerated performance and retained a confidence in reliability not otherwise possible.

Goodyear has had considerable experience, for instance, in the use of polymeric cloth and elastomer coatings. Extensive test and fabrication data are available for such materials as cotton-neoprene, nylon-neoprene, Fortisan-neoprene (Celanese Corp.) and Dacron-neoprene (DuPont). Data on the use of these materials with other elastomers such as butyl are also available. Expandable structures are fabricated with single-ply and multiple-ply fabrics, depending on the stiffness or strength requirements. Multiple-ply fabrics are cemented together at certain angles between the warp threads of successive layers to provide torsional stiffness or improved strength. Where strength is desired in only one direction, cord-type fabrics have been developed to optimize weight and volume. These fabrics consist of polymeric cords or filaments placed side-by-side and held together with the elastomer. The properties of the fabrics available for the applications mentioned previously are indicated in the table below. These values are meant only to be representative, since in many cases several materials would offer suitable solutions to the problem, whereas material choice may have been dependent on availability of special consideration.

Generally speaking, the polymeric fabrics cannot withstand temperatures

greater than 300 to 400 F. However, glass-fiber fabrics have been tested to temperatures of approximately 1000 F. It was found that the Sil-Temp cloth (Haveg Corp.), a newly developed material, had fairly good strength characteristics above 1000 F after a two-hour exposure. Additional developments in this polymeric fabric area could lead to a material suitable for applications in the 1000 F temperature range.

In defining a fabric for a specific application, the proper weave and yarn must be chosen to obtain acceptable permeability, coating adhesion, joining, flexibility, and structural characteristics, to name a few. The following table shows the type of weaves generally considered and their ratings for various characteristic properties (the lower the number, the better the value).

Type of Weave	Tear Resistance	Coating Support	Gas Barrier
Plain (1 x 1)	3	3	1
Basket (2 x 2; 3 x 3)	1	1	3
Twill (2 x 2)	2	2	2

It is readily apparent that the twill weave is a good compromise for the properties considered. Flexibility of the cloth is dependent on whether the yarn consists of a single filament or twisted multiple filaments, in addition to the tightness and type of weave.

In the development of a fabric suitable for re-entry applications, super alloys and refractory metals were investigated with respect to strength, flexibility, strength-to-weight ratio, packageability, etc. It was also important to consider the material availability, workability and growth potential, in addition to its high-temperature characteristics. For this reason Inconel X and René 41 were given the most consideration. Since for many representative applications a maximum temperature of 1500 F proved adequate, it was decided to select René 41 as most promising, as considerable wire-drawing experience was

Characteristics of Polymeric Fabrics

Fabric Type	Total Weight oz/yd	Working Pressure	Tensile Strength lb/in.
Nonrigid Airship	12-26	1-4 in. H ₂ O	50-550
Fabric Radomes	37	13 in. H ₂ O	700
Inflatoplane	18	7 psi	450
Drag Balloon*	4-6	1-2 psi	182
Space Station	86	7 psi	2000

* Ballute.

available and fabrication methods did not seem insurmountable. It is likely that metals such as Udimet 700 (Kelsey-Hayes Co.) will replace René 41 in some applications as more fabrication experience is obtained.

René 41 wire of 0.0016-in. diam has been woven into 100 x 200- and 200 x 200-count cloth (warp x fill count per inch) in plain, twill, and basket weaves. Representative re-entry-type tests were conducted on these materials with suitable surface coatings; but most data is available on the 200 x 200 plain weave, which was readily available early in the program. One other significant result is that the tear strength of woven cloth is greater than that of stainless-steel shim stock of three times the cross-sectional area. The resulting fabric chosen for this re-entry drag body application was 200 x 200 plain-weave René 41 wire cloth of 0.0016-in.-diam yarn weighing about 13.60 oz/yd² with an included coating weight of 8.0 oz/yd² applied to one side.

For high-temperature applications, the coating of a metal cloth must provide protection from oxidation in addition to acting as an inflation-medium barrier. The coating material must have good adhesion to the basic material under static and dynamic conditions and good flexibility to facilitate packaging. Goodyear has conducted tests on several hundred coating materials suitable for both high- and medium-temperature fabrics.

Permeability tests were conducted for a specific heat cycle ($T_{max} = 1500$ F) at helium pressures of $\frac{1}{2}$ to 1 psi. These exploratory tests indicated that Goodyear coatings CS105 and CS107 were the most promising of the 24 types tested. Basically these coatings consist of a mixture of silicone elastomer S2077 and a glass enamel. Controlled tests were conducted on CS105 coating to define its characteristic changes through a temperature range of -320 to 1800 F. The coating retained some degree of flexibility throughout the temperature range tested.

Similar tests of coatings on glass-fiber cloth showed that type-B silicone was very effective up to the 1000-F test.

Present fabrication techniques for metal-fabric structures consider resistance welding, high-temperature adhesives, ultrasonic welding, and brazing, to name a few. Joint efficiencies ranging from 70 to 90% have been obtained with small-diameter René 41 wire cloth during the preliminary development phases of recent programs.

Airmat itself has been constructed of such materials as nylon, Dacron, glass fibers, and metal wires for specific

applications. The thickness has been varied from 0.4 to 15 in. for the polymers and up to 9 in. for the metal wires for constant cross sections. The maximum width of cloth on present looms is 54 in. However, future plans for a 120- to 240-in. size seem reasonable. The number of drop threads may vary from 8 to 90 per square inch, depending on operating pressures and surface smoothness; but 32 drop threads per square inch are generally used. The present plow looms have a maximum weaving distance of 3 in. between face cloths; however, greater depths in increments of loom capability are achieved through simple fabrication schemes.

The recommended operating pressures for Airmat vary from $\frac{1}{15}$ to $\frac{1}{3}$ of the burst pressure, depending on such requirements as time, weight, volume, cycling, etc. The maximum bending moment which can be resisted without wrinkling of Airmat is determined by the formula $M_{max} = \frac{1}{2} pt^2$ (lb-in./in. of width) where p is the operating pressure in psi and t is the Airmat thickness in inches. The thickness of the cover plies is determined by stresses due to pressure and buckling or twice the pressure stress, since these two stresses are equal at the wrinkling condition.

The total weights range from 20 to 90 oz/yd² with the elastomers and cover plies usually representing about 50 to 75% of this weight. A new development utilizing a film coating of Mylar (DuPont) and Videne (Good-year Tire and Rubber) has cut the cover-ply weight to about 20% of the total Airmat weight. This should open new space-application areas.

Goodyear has been in the plastic-

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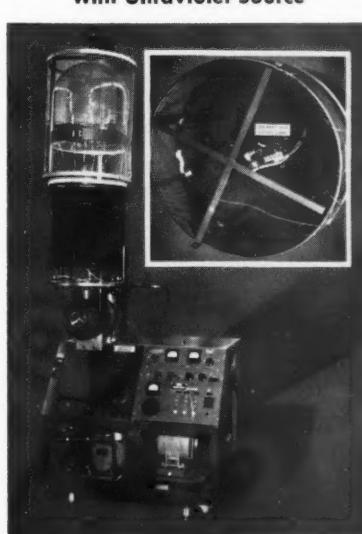
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film field since the early 1930's developing such products as Pliofilm, Vita-Film, vinyl film, Videne A, and Videne TC. The company has also developed film laminates, for example, laminates of Mylar to cloth or foams of different density and thickness as a means of improving general performance.

Films have been considered and used for such applications as high-altitude balloons, deceleration balloons, space antennas, re-entry bodies, solar collectors, and other space applications. Mylar, Videne, polypropylene, and polyethylene have been investigated for these applications. The properties of these materials are readily available in the company literature and will not be discussed here.

Considerable development work has also been done on polyurethane and polyether foams. The use of flexible and rigid foams is being considered as a rigidization method for expandable structures. Techniques have been developed to successfully deploy, pressurize, and foam-rigidize expandable structures in simulated space environments. Foam densities on the order of 0.10 lb/ft³ have been achieved. A laminate material of Mylar film and lightweight foams is being considered as a means of rigidizing large light-



High-Vacuum Bell Jar
With Ultraviolet Source

weight space structures. Laminates of films and aluminum foil also seem suitable for these applications.

Verification of physical properties for expandable structures generally can be made using the same techniques and apparatus as that employed in rigid-structure testing. Since they are usually composites, however, this requires determination of the individual constituent properties as well as the final composite performance.

The bell jar and related equipment shown on page 93 are used at Goodyear to subject expandable materials to combined high-vacuum, ultraviolet-radiation, and elevated-temperature conditions. Short- and long-time tests have been conducted on elastomers, films, foams, and coated wire cloth to determine the effects of the simulated spatial environment on weight and performance characteristics.

The Pyrex bell jar is 18 in. in diam and 30 in. high. It is possible to obtain pressures of approximately 5×10^{-7} mm of Hg (an altitude of approximately 150 mi) with the use of the liquid-nitrogen trap. A GE quartz tube, mercury-vapor lamp is used as the ultraviolet source radiating in the wavelength band of from 2200 to 4000 Å. The ultraviolet lamp is mounted vertically along the axis of the bell jar. Water-cooled coils are used to maintain specimen temperatures in the 55- to 300-F range. The specimens are arranged in the bell jar so that some are exposed to combined vacuum and ultraviolet light while others are exposed to the vacuum only.

Tests on neoprene and butyl elastomers over an approximate 300-hr period indicate that a rapid weight

loss of about 5% was experienced only during the first 100 hr where test temperatures were maintained at 155 F. This is apparently due to the early outgassing of the more volatile, low-molecular-weight constituents of the material. An increase in ultimate tensile strength (11 to 25%) and stiffness (10 to 35%) was noted for these test conditions.

High-vacuum (5×10^{-6} mm Hg) and ultraviolet tests were conducted for periods of 5 and 15 days on René 41 wire cloth coated with the Goodyear elastomer CS105 at the specimen temperature of 300 F. Except for a slight discoloration of the coating, due to the ultraviolet exposure, no deteriorative effects were noted.

The apparatus shown schematically below is used to determine fabric permeability under controlled conditions of temperature and pressure. The fabric sample is exposed to a controlled helium pressure on one side and a heated vacuum environment on the opposite side. The specimen temperature is controlled by the quartz heating lamps to simulate a representative temperature-time cycle. A constant pressure difference is maintained across the specimen, and the rate of leakage of the helium through the specimen is measured with a Helium Mass Spectrometer specifically designed to analyze gas samples. Plots of helium concentration versus time permit determination of rate-of-change of helium concentration in the chambers as a measure of the fabric permeability.

René 41 wire cloth with filaments of 0.0016-in. diam was tested for plain, twill, and basketweave conditions at a

representative re-entry temperature cycle with a maximum temperature condition of about 1500 F and a time cycle of 5.5 min. The helium permeability ranges from 0.002 to 0.02 cu ft/sq ft/min for a pressure differential of 0.5 psi with the plain weave being the least permeable of the three types and the basketweave being the most permeable for similar coating conditions. All the specimens showed practically no helium leakage until the maximum temperature condition was attained. At maximum temperatures the leakage rate increased and stayed practically constant for the remainder of the test.

Only enough elastomeric coating is applied to maintain a reasonable rate at operating pressures to minimize over-all vehicle weight.

The emissivity of René 41 wire cloth coated with CS105 elastomer was determined with the permeability apparatus, slightly modified. A 3-in.-diam-sample opening was used, and both sides of the sample were subjected to vacuum conditions of about 0.1 in. of Hg pressure (an altitude of about 120,000 ft). The quartz lamps were used to heat one side of the sample, while the other side was turned to a thermopile. A metal plate was placed between the lamps and the sample to provide diffused heating.

A comparison of the time rate-of-change of the thermopile voltage for the fabric sample and a standard black body (oxidized Inconel disk coated with camphor soot) at various temperatures resulted in the emissivities shown below.

Emissivity

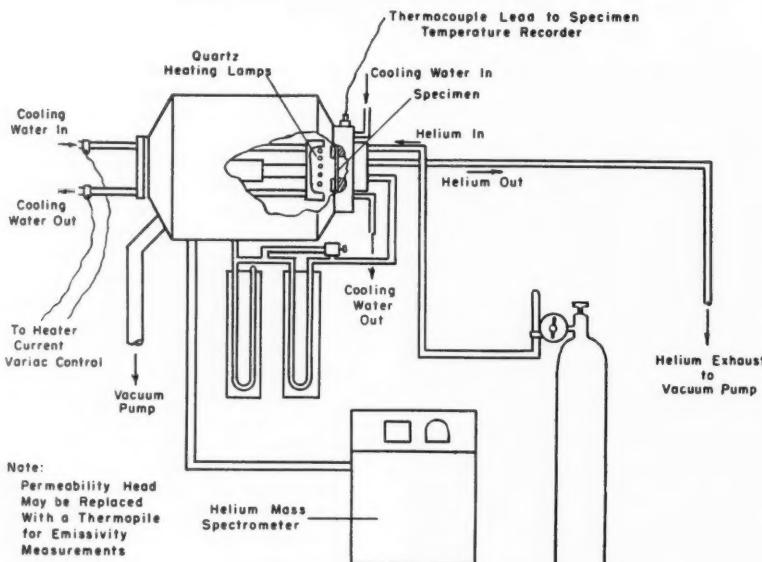
Temp (F)	Opposite Surface	
	Coated Surface	Opposite Surface
500	0.63	0.72
800	0.82	—
1000	0.92	0.95
1200	0.92	0.95

The opposite surface possessed normal strike-through characteristics for an 8-oz/yd² coating of elastomer.

In the development of the expandable structure concept for space application Goodyear Aircraft has demonstrated that polymeric fabrics, long useful for low-speed vehicles and ground applications, are now finding a place in high-speed and high-altitude applications and as space-vehicle components.

It has also been demonstrated that application of lightweight low-density structures can limit re-entry temperature to 1500 F and make this operation feasible within the present state of materials development. ♦♦

Diagram of Fabric-Permeability Apparatus



International Scene

(CONTINUED FROM PAGE 15)

delegates at a dinner. On March 6, the Mayor of Paris held a reception in the City Hall. A cocktail party for the delegates of the French aeronautics community was given by F. J. Malina, deputy director of the International Academy of Astronautics on March 5. On the evening of March 6, the officers of the Academy of Aeronautics were entertained at dinner by von Karman.

Niels Bohr, the world-famous Danish physicist, was elected the first Honorary Member of the International Academy of Astronautics. The Academy elected the following new members:

Basic Sciences Section. Julius Bartels, Univ. of Göttingen (West Germany); David R. Bates, Dept. of Applied Mathematics, Queen's Univ., Belfast (Great Britain); L. Biermann, director, Max Planck Institute for Astrophysics (West Germany); Sydney Chapman, High Altitude Observatory, Boulder; Herbert Friedman, Atmosphere & Astrophysics Div., U.S. Naval Research Laboratory; Leo Goldberg, Harvard College Observatory; Homer E. Newell, deputy director, Office of Space Flight Programs, NASA; Fred L. Whipple, Harvard College Observatory.

Engineering Sciences Section. Adolph Busemann, Langley Research Center; Elie Carafoli, director, Institute of Applied Mechanics, Bucharest (Rumania); Luigi Crocco, director, Jet Propulsion Center, Princeton Univ.; Kraft A. Ehricke, Convair Astronautics Div.; Antonio Ferri, Polytechnic Institute of Brooklyn; Arthur R. Kantroutz, director, Avco Everett Research Laboratory; Michael J. Lighthill, director, Royal Aircraft Establishment, Farnborough (Great Britain); Maurice Roy, director, ONERA (France); Howard S. Seifert, Stanford Univ.; Ernst Stuhlinger, director, Research Projects Div., NASA, George C. Marshall Space Flight Center; Martin Summerfield, Princeton Univ.

Life Sciences Section. Robert Grandpierre, director, Aviation Medicine Research Center (France); U.S. von Euler, Dept. of Physiology, Karolinska Institute (Sweden); Ashton Graybiel, director of research, U.S. Naval School of Aviation Medicine; Tomaso Lomonaco, director, Research Center for Aviation Medicine (Italy); Rodolf Margaria, former director, Research Center for Aviation Medicine (Italy); Hermann J. Schaefer, Research Dept., U.S. Naval School of Aviation Medicine; Gustav Schubert, Physiological Institute, Univ. of

Vienna (Austria); Col. John P. Stapp, Aerospace Medical Center, Brooks Air Force Base; Air Comm. W. K. Stewart, RAF Institute of Aviation Medicine, Farnborough (Great Britain); P. M. Van Wulften Palthe, National Aeromedical Center (Netherlands); Sir Harold E. Whittingham, chief medical officer, BOAC (Great Britain).

The International Institute of Space Law considered questions propounded to eleven Working Groups and reported significant progress in the solution of urgent questions concerning airspace matters. [See *Astronautics*, November 1960, p. 46] Elected to the Executive Committee, the governing body of the Institute, were Antonio Ambrosini of Italy; Eugene Pepin of Canada; and Vladimir Kopal of Czechoslovakia. A memorial was adopted praising the contributions of John Cobb Cooper, and a resolution was passed defining his duties as director of research of the Institute. Sessions of the Institute spread over a period of two days.

and well-organized society, the officers of the ASC and the CAS have for more than a year been attempting to work out the basis for a merger of both groups into a single, integrated society which would be national in scope. However, those negotiations have not yet produced the desired result.

Interest in organized rocket and space exploration activities continues to grow at a rapid pace in all parts of the globe. Applications for admission to the IAF have been made by four new societies and more are expected to apply at the 12th International Astronautical Congress of the IAF in October in Washington. Applications for admission were received from the Cyprus Astronautical Society, the French Center for Astronautical Research, the French Association for Cosmic and Astronautical Study and Research, and the Mexican Society for Interplanetary Studies.

The International Radio Consultative Committee (CCIR) will meet in 1962 to consider technical questions related to space telecommunications. U.S. Study Group IV, under the direction of John P. Hagen of NASA, has been working for a year on the collection and analysis of necessary technical data for presentation in 1962.

While the preparation for world regulatory conferences goes on, practical uses of radio in space are being expanded significantly. In recent weeks, for example, AT&T and ITT Labs have both received from FCC experimental authorizations to study the use of active and passive earth satellites in communication systems. Optimistic predictions have been made by the major carriers as to the expected date of commencement of regular operations. ♦♦♦

Dates Set for European Space, Rocket Meetings

PARIS—Dates have been set for three European meetings devoted to aeronautics and rocketry this June. A meeting of the International Academy of Astronautics on Earth Satellite and Re-Entry Trajectories, to be monitored by Paul Libby, will be held in Paris June 19–21, and will be followed June 23–24 by a Franco-Italian Colloquium on Sounding Rockets. The First European Symposium on Space Technology will be held in London June 26–28.

—A. K. Oppenheim

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Photo of Rocket Chamber courtesy of Aerojet-General Corporation



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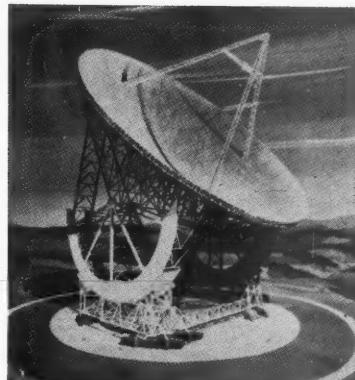
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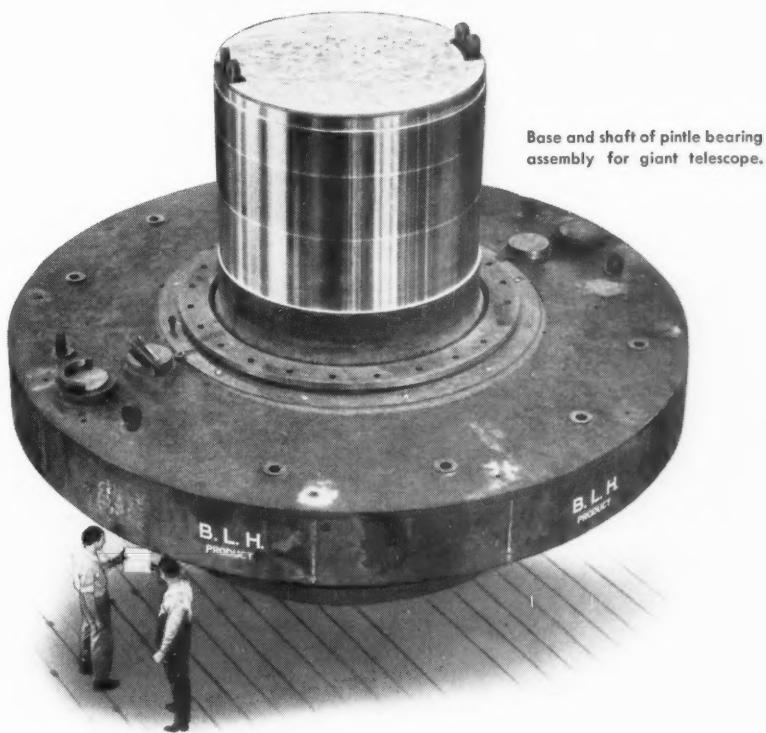
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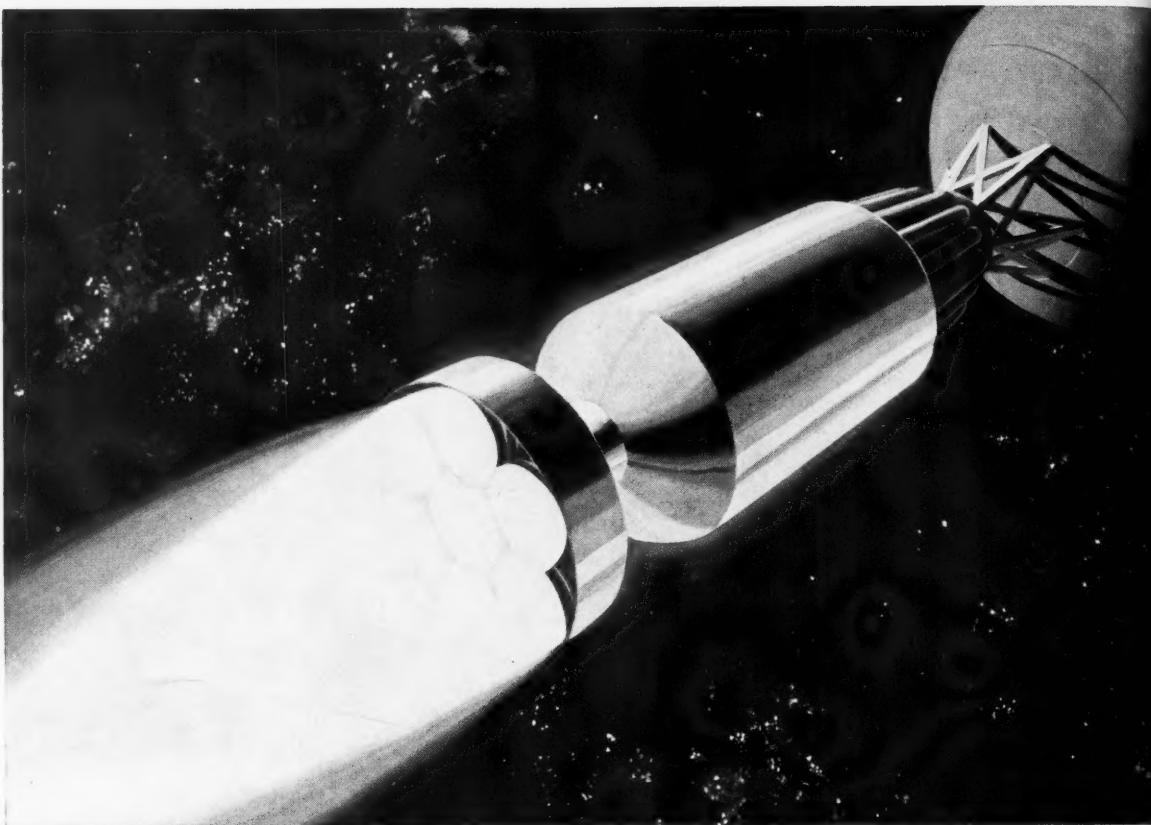
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